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OUR EARTH A GREAT MAGNET.*

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OUR Earth a Great Magnet! This dictum was first pronounced upon the unsuspecting Earth by the immortal William Gilbert, sometime body physician to Queen Elizabeth. Of him, the "father of magnetick philosophy," Dryden predicted:

> Gilbert shall live till lodestones cease to draw,
> Or British fleets the boundless ocean awe.

In his famous treatise on the magnet, published in 1600, Gilbert summed up the knowledge which he had gained from laborious magnetic researches in the following words: "*Magnus magnes ipse est globus terrestris*" ("The terrestrial globe itself is a great magnet"). Three centuries have elapsed since then, and we can only say: If the Earth is not a magnet, it certainly acts like one.

The Earth a Great Magnet! Our Earth we think we know something of—but *what is a magnet?* To get our subject fairly launched we at least must know what we are going to talk about. Clear vision demands clear definition. "A definition is the resolu-

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tion of a complex idea into the simple elements which compose it." First of all, then, patterning after Gilbert, we must declare, in familiar language, what are the apparent common virtues of a magnet; afterward numerous subtleties are to be laid upon, by fitting terms and devices; we shall even penetrate, if we can, to the very interior of the magnet's "wizard cell." To do this, let us begin with the natural magnet, or lodestone, a blackish-looking mineral, known to the geologist as magnetite, a specimen of which from Magnet Cove, Arkansas, I hold in my hand. Three centuries ago this stone was so highly prized that it was often used as a setting in rings. Sir Isaac Newton, for example, exhibited with considerable pride a particularly powerful bit of lodestone set in a ring.

EARLY MAGNETIC DISCOVERIES.

The earliest speculations with regard to the nature of the lodestone, or magnet, were those of the early Greeks, in whose philosophy the magnet played an important part. The "father of philosophy," Thales of Miletus, who lived some twenty-five centuries ago, is said to have been the first to disregard the old belief in outside supernatural influences, and to have sought for the cause within the thing itself. He assumed the magnet to have a "magnetic soul, or a virtue," inherent in itself, whereby it could move the "beloved iron." Very naturally this led him to the idea of the soul within man.

Later Plato, another Greek philosopher, having had his attention drawn to the experiment of the "Samothracian rings," performed by the early iron-workers in Samothrace, came to a similar conclusion. "There is a divinity," he says, "moving you, like that in the stone which Euripides calls a magnet, but which is commonly known as the stone of Heraclea. For that stone not only attracts iron rings, but also imparts to them similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another, so as to form quite a long chain, and all of these derive their powers of suspension from the original stone. Now this is like the Muse who first gives to men inspiration herself, and from those inspired, her sons, a chain of other persons is suspended, who will take the inspiration from them."

Seeing then the part played by the magnet in the old Grecian philosophy, we must not be surprised, since philosophy has ever

permeated and influenced the world's writings, that the magnet has also left its impress upon literature. Thus "in the love of the magnet and the iron a new metaphor is given to the world which even the greatest of its poets has not disdained to use," and in quotations from famous writers we readily find clues to all the chief properties of the magnet. Says Plutarch, for example, "Like as iron drawn by a stone often follows it, but also often is turned and drawn away in the opposite direction, so also is the wholesome good and regular motion of the world." This quotation will serve to emphasize to us the dual property of the lodestone —that of drawing unto itself the all-conquering iron, and that of repelling substances which are in a "magnetic" condition (observe I am still using words before having defined them). This dual property of the lodestone, as just shown you, is called the property of polarity.

As time went on men surrounded the mystery of the magnet with greater mystery. Chief among the fables which sprang up was the long-believed one of the Magnetic Mountains, which Ptolemy located in the China Sea, on islands which he called the Manioles. He says that ships going too near them are stopped, and hence must be put together with wooden nails, in order that the Heraclean stone, which grows there, may not attract them. (Here we have the legendary ancestors of the non-magnetic ship *Carnegie*.) The idea of magnetic mountains, while at the time fanciful, has some basis in the fact that widely distributed over the Earth there are regions of intense local attraction of the compass, generally ascribed to magnetic iron deposits. The isle of Bornholm, in the Baltic Sea, where the American cotton ship *Evelyn*, a few years ago, met her fate, is an intense centre of local attraction of the compass.

One of the new terms occurring in Gilbert's book, which by the way was originally published in Latin, was *coitio*, a coming together. By this word Gilbert wished to convey the idea of action and reaction, later enunciated more clearly by Newton. Thus it was not simply the iron that was drawn to the stone, or, as you have just seen, the iron filings to the magnet, but also the stone or magnet to the iron. Sir Thomas Browne picturesquely expressed this idea thus:

"If in two skiffs of cork, a Lodestone and Steel be placed within the orb of their activities, the one doth not move the other

standing still, but both hoist sayle and steer unto each other; so that if the Lodestone attract, the Steel hath also its attraction for in this action the Alliency is reciprocate, which jointly felt, they mutually approach and run into each other's arms."

The oft-quoted expression, "True as the needle to the pole," which first occurred in a poem by Barton Booth, about two centuries ago, will serve to indicate another striking fact regarding the magnet; namely, if it be mounted so as to turn freely about a vertical axis, after repeated vibration to and fro, it finally settles down in a definite direction, as shown by the lodestone you see suspended. Displace it, and it returns to the same position as before. The direction so persistently assumed is approximately north and south—not exactly so; and here our poetic quotation as to the needle being true to the pole—geographic pole—is somewhat at fault.

We do not know just when this *directive property*, or *property of directivity*, of the natural magnet was discovered, or at what time man learned the art of making artificial magnets. According to early legends, the Chinese had made use of the directive property of the magnet in land journeys and in the orientation of buildings and sites, long before it had become known, in about the twelfth century A.D., to the people of the Occident.

And now permit me to call attention to the origin of the word "lodestone"; it comes from the Icelandic verb "leid," meaning to lead or point somewhere, or from the Anglo-Saxon "ladman," a leader. The term "magnes" may have originated from the name of the discoverer of the natural magnet or from the city, Magnesia, in Ionia, Asia Minor, where it "grew."

Though we have not as yet defined what a magnet is, we have become familiar by quotation and experiment with its three fundamental characteristics: (1) property of attraction; (2) property of repulsion and polarity; (3) property of directivity—the magnet attracts, it repels, and it points in a certain direction.

BIRTH OF THE SCIENCE OF TERRESTRIAL MAGNETISM.

But so far we have been dealing with the magnet in its simplest form. We come now to a consideration of a far greater and more complex magnet—our Earth. It was while endeavoring to explain the directive property of the lodestone, or of the magnetized needle, that Gilbert reached the hypothesis that the Earth itself is a great

round lodestone. His experiments, on which it is said that he spent £5000, had shown that only a magnet could act on another magnet in the manner revealed by the compass needle.

Since Gilbert's time, however, we have learned that the production of magnetic effects does not necessarily depend upon a substance like the lodestone. Oersted, a Danish physicist, discovered, in 1819, that a compass needle tends to set itself at right angles to a wire carrying an electric current. This discovery gave birth to the science of electromagnetism, and taught us a new way of making a magnet—the so-called electromagnet, of which you have a specimen before you.

From Oersted's experiment we know now that the Earth need not be a great lodestone to be a magnet, or act like one. Thus electric currents circulating within the Earth, approximately at right angles to the compass direction, or from east to west, would have the same effect. Were we to attempt to make at present any improvement on Gilbert's hypothesis, we should say that the Earth is either a great magnet or a great *electromagnet*. But still we have not as yet defined a magnet, nor, for that matter, an electromagnet. However, observe that we are engaged in the execution of that simple process referred to at the beginning of the lecture—the resolution of the complex idea of a magnet into its simple, constituent elements.

THE EARTH'S MAGNETIC LINES OF FORCE.

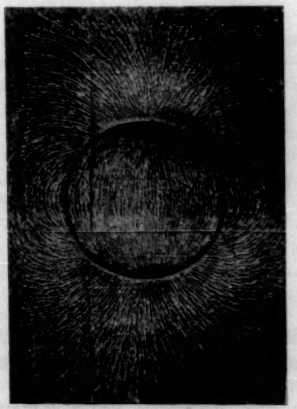
To assist him in the interpretation of magnetic and electric phenomena, that skilful investigator, Michael Faraday, introduced, a century ago, the happy terms, "magnetic field" and "magnetic lines of force." These concepts, in some form, though vague, had already been in the minds of the early writers. Thus Robert Norman, who discovered the dip of the magnetic needle in 1576, says, in his memorable book, "The Newe Attractive": "And surely I am of opinion that if this Vertue could by any means be made visible to the Eye of man, it would be found in the spherical forme, extending round about the Stone in great Compasse, and the dead bodie of the Stone in the middle thereof."

On the screen you have projected the image of a bar magnet. Let us see what happens when there is brought near it some iron filings. See how the tiny filaments gradually arrange themselves around the magnet in a beautiful series of curves, which start and

end at certain points, called the poles. Look at the filaments; what is controlling them? How fondly the magnet holds them in its embrace! Is it then surprising that the lodestone was also called the lovestone, a meaning still preserved by certain countries in their names for the magnet? Thus the French still call the magnet *l'aimant*, or the loving one.

If every magnet is surrounded by lines of force, such as have just been traced out for us on the screen, then, since the Earth

FIG. 1.



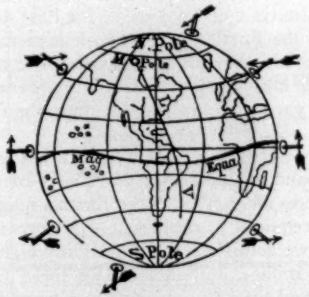
Magnetic lines of force as they would envelop the Earth if its magnetic axis were coincident with its axis of rotation. [The Earth's magnetic poles are, on the average, about 1200 miles from the geographic poles, and they are not diametrically opposite each other. A straight line connecting the magnetic poles would pass through the Earth 750 miles distant from the centre.]

acts like a magnet, it also must be enveloped by magnetic lines of force. The picture next seen on the screen (Fig. 1) shows how these lines of force would envelop the Earth were its magnetic axis coincident with the axis of rotation, instead of inclined to it. We see that the lines of force enter the magnetized sphere at various angles of inclination or dip, the steepness diminishing steadily from the poles to the equator. The next slide (Fig. 2) will give you some idea of the irregularity of the actual magnetization of the Earth.

To demonstrate the existence of the Earth's magnetic lines of force passing through this room, through your body and through mine, we will make use of the discovery which founded the branch of electrical science known as magneto-electricity. The operator is holding in his hand a coil of copper wire connected with a galvanometer, from whose mirror a spot of light is now thrown on the screen; note that the spot is standing at a certain number of the scale above it. He now moves the coil so that it cuts across the lines of force of the electromagnet near by. See the sudden movement of the spot of light!

Using a similar coil, let him next give it a quick turn in the

FIG. 2.



The North Magnetic Pole is about in latitude 70° north and longitude 97° west, and the South Magnetic Pole is about in latitude 72° south and longitude 153° east. [The irregularity of the Earth's magnetization is also shown by the departure of the magnetic equator from the geographic equator. The arrows show how a dipping needle would point in different parts of the Earth.]

Earth's magnetic field. Observe that the spot of light again moves. The largest movement is observed when the coil is turned with its axis at right angles to the magnetic lines of force of the Earth. And if the operator turn the coil so that its axis is parallel to the terrestrial lines of force, there would, eventually, be no movement of the spot.

The cause of the movement of the spot in both experiments was the generation of a current of electricity by the rotation of the coil in the magnetic field. In the first experiment the magnetic field was that around an artificial magnet; in the second experiment it was the Earth's magnetic field.

You have thus had demonstrated to you the existence of a magnetic field surrounding the Earth, and have also been shown the principle on which one instrument, the so-called earth inductor, for measuring the dip of the magnetic needle, depends (see Fig. 9, B).

HOW STRONG A MAGNET IS THE EARTH?

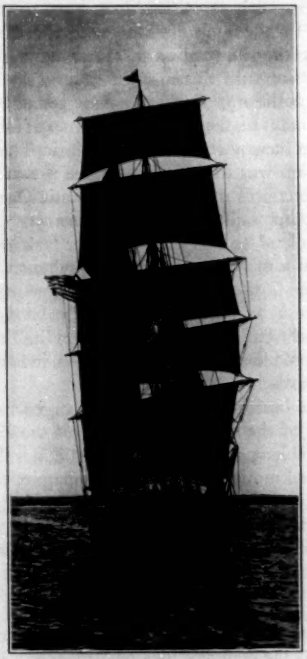
If the magnetism of the Earth were uniformly distributed throughout its volume, then the magnetic intensity of each cubic yard would be equal to six one-pound steel magnets, like the one I hold in my hand, which is fourteen inches long, one inch wide, and one-quarter inch thick. However, at a depth of ten to twelve miles below the surface, the temperature would be so high that magnetized substances could not exist, for heat destroys magnetism. Hence, if the Earth's magnetic phenomena are caused by magnetized materials, they probably would have to be confined to the outer ten-mile layer of the crust, and the average magnetic intensity per cubic yard would be equal to more than that of six one-pound magnets.

Suppose there were no interior heat and that we could concentrate our one-pound magnets all at the centre of the Earth, with their magnetic axes all parallel to the Earth's magnetic axis, how many would be required to cause magnetic forces on the Earth's surface such as we actually measure? Only eight thousand five hundred million million millions! Place these 14-inch magnets in line, end on, and they would reach to a point in space distant from us twenty thousand million times that of the Sun from the Earth, or about seventy thousand times that of the nearest star, Alpha Centauri, whose light requires four years to reach us. As you know, light travels one hundred and eighty-seven thousand miles per second. Looked at in the way just stated, the Earth appears to us a very strong magnet, indeed.

By modern methods we could magnetize a bar of specially-prepared steel so that it would be four and one-half times stronger than the specimen used for illustration. The average intensity of magnetization of the Earth's substance, for the entire volume, would be only about 1/10,000 that of very highly magnetized steel. This fact led Professor J. A. Fleming to remark: "Taken as a whole, the Earth is a feeble magnet. If our globe were wholly made of steel and magnetized as highly as an ordinary steel-bar

magnet, the magnetic forces at its surface would be at least one hundred times as great as they are now. That might be an advantage or a very great disadvantage."

FIG. 3.



The non-magnetic yacht, *Carnegie*, setting out on her cruises in 1909. [In October, 1909, she followed practically the same track from St. Johns, Newfoundland, to England, as that of Halley's ship, the *Paramour Pink*, in 1699.]

CHANGE OF EARTH'S MAGNETISM WITH TIME.

In the year 1634, Gellibrand, professor of mathematics at Gresham College, England, found that at London the north end of the compass pointed only a trifle over 4° east of north, whereas,

fifty-four years before, in 1580, it had been pointing as much as 11¼° east of north. In 1658, the year of Cromwell's death, the compass pointed truly north and south; in 1812 it pointed 24° west of north, and now it points only about 16° west of north. There is thus made apparent not only the need of magnetic surveys, but likewise their repetition, from time to time, in order to obtain the data for the revision of magnetic charts.

Another striking illustration of the amount of change in the Earth's magnetism with the lapse of time is the following one: In the year 1698 the ship *Paramour Pink* set sail from England, under the command of the noted astronomer, Halley, whom you may recall from the comet named after him. The prime purpose of this expedition was to find out, for the use of mariners, how the compass direction varies over the Atlantic Ocean. Two centuries later another sailing vessel, the *Carnegie* (Fig. 3), sailed from Newfoundland, to carry out the same task begun by Halley, but this time on a more systematic, comprehensive, and accurate basis. Had the *Carnegie* followed the same magnetic courses across the Atlantic as were held by the *Paramour Pink*, instead of coming to anchor at Falmouth Harbor, on the English Channel, the *Carnegie* would have made a landfall somewhere on the northwest coast of Scotland!

Some of the best minds have been engaged in trying to discover the cause of the mysterious change of the Earth's magnetism, but the problem, in its entirety, is still unsolved. Both as regards the actual motions of the Earth's magnetic poles with the lapse of years, and the precise cause or causes thereof, we may still say with Halley that these are "Secrets as yet utterly unknown to Mankind, and are reserv'd for the industry of future ages."

WHAT IS A MAGNET?

We are now through with the serious part of the lecture. Having resolved the complex idea of "magnet" into the simple elements composing it, and having familiarized ourselves with the chief characteristics as represented by magnets of various kinds—the lodestone, the bar-magnet, the electromagnet, and even the Earth-magnet—the rest is easy, and we can immediately give the answers to our questions: What is a magnet? What is magnetism? and What is a magnetic field? We are peculiarly

fortunate in that we may avail ourselves of the definitions of the most eminent astronomer of his time. In the latter years of his life he sought the aid of magnetism to solve some of the great outstanding problems of astronomy—the irregularities in the motions of the Moon, for example, which apparently could not be explained on the gravitation theory alone. I refer, of course, to the late lamented Simon Newcomb.

Professor Newcomb was given general oversight of the definitions in physical science for a certain dictionary. Taking exception one day to the definitions for magnet and magnetic force submitted to him, he was requested by the assistant editor to try his hand at framing better definitions. After alternately writing and erasing for an hour or more, the astronomer, with a hearty laugh, handed in the following definitions: "*Magnet:* a body capable of exerting magnetic force; *Magnetic Force:* the force exerted by a magnet!"

Could you imagine any more satisfying definitions? Yet to show you how inappreciative literary folk are of exactness in science, I have but to cite you a quotation from Ambrose Bierce's Cynic's or Devil's Dictionary. Here we find the following definitions: "*Magnet:* n.—Something acted upon by magnetism; *Magnetism:* n.—Something acting upon a magnet." Bierce then cynically remarks: "These two definitions are condensed from the works of 1000 eminent scientists who have illuminated the subject with a great white light, to the inexpressible advancement of human knowledge."

Alas! it is only too true that, in spite of centuries of research, we can not as yet say precisely what magnetism really is, nor do we know exactly by what physical process a substance is put into the state we term "magnetic." But, for that matter, can any one tell us precisely what electricity is, or even what is the force of gravitation? In this connection, the cynic above quoted says: "Newton discovered that an apple will fall to the ground, but was unable to say why; his successors and disciples have advanced so far as to be able to say when." Indeed, it is questionable whether Man, whom a German philosopher named "*das Ursachenthier*"—the animal ever incited and stimulated by his inquisitiveness to search out the cause of things—will ever be able to determine the ultimate causes, or, shall we say, the cause or origin of Nature's primal forces. But let that not discourage us. Have we not,

each one of us, at some time or another, felt the truth of Robert Louis Stevenson's words:

> To travel hopefully is better than to arrive,
> And the true success is labor.

Let us then arouse ourselves, and, like "true philosophers, ingenuous minds," leave now our books and indoor experiments, and go out and deal with things as revealed by Nature at large with respect to the great magnet, our Earth.

In doing this, let us ever keep in mind that this great Earth of ours is not bounded by the surface we tread, nor even by the

FIG. 4.

The Aurora Borealis as first photographed by Professor Carl Stoermer.

farthest atmospheric levels above us; that there is besides a *something*, inseparably bound up with the Earth, extending far out into illimitable space, exceedingly tenuous and ordinarily invisible, except when made apparent to us by the beautiful phenomenon of polar lights, whose flickering lights and shooting rays arrange themselves in accordance with the Earth's magnetic lines of force, and "dance in rhythm with the quivering needle" (Fig. 4). As has been well said: "Our globe, as it spins through space, is clothed, as it were, in a gossamer garment woven of lines of magnetic force, and this little trembling needle serves as a sensitive finger, whereby we track out the path of these invisible clues, and, confidently determining our direction, though wandering over

wide waters, wrapped, it may be, in darkness or in storm, are enabled thereby to establish a continual intercourse between all portions of the globe."

THE COMPASS IN NAVIGATION.

An old seafaring man from down East, when asked how he managed to get about, having never studied navigation, naïvely replied: "I know 'nough navigation to git out o' Boston harbor, and then I ken go where I durn please." Most of us are not in the fortunate position of this happy mariner who can go where he pleases. When you or I take an ocean liner we usually must go to some definite place, and we regard our good captain as not proficient if he does not succeed in getting us there safely by the most direct path and in the quickest possible time. What does this imply? Our palatial ship is strongly built of most durable steel, every modern electrical contrivance known to man is at our command, we are being impelled through the seas by the most powerful steel engines of the time, we have besides our cargo of precious human freight a great amount of merchandise, consisting, perhaps, of masses of iron and steel. As we stroll the hurricane deck on a sunny day we note how eager are the ship's officers (Fig. 5) to get their sights on the Sun for determining both the ship's position and the course to be followed to our invisible port far beyond the horizon. What serves to guide the helmsman in holding the ship's course during the intervals between these astronomical observations, or what will the mariner do if clouds and rain obscure Sun and stars?

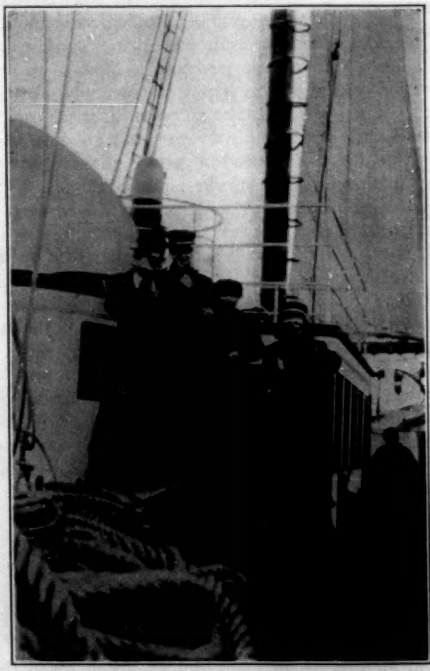
> No ship could sayle on seas,
> her course to runne aright,
> Nor compass shew the ready way,
> were Magnes not of might.

So says Robert Norman, in 1581, in his quaint poem, entitled, "The Magnes' or Lodestone's Challenge."

If, then, in spite of the "constant inconstancies of the magnetical needle," and the use of every modern contrivance, the mariner must still rely chiefly on the compass to guide him across the trackless seas, and the explorer must depend on the needle to direct him through the deep jungle and over the arid wastes, how important it is that this compass should be true and that the "vagaries of the needle" should be definitely known.

The falsifier of the compass today is not the sailor with the garlic breath, as was the belief four centuries ago, but our steel ship and the iron and steel carried on board. Magnetism acts

FIG. 5.



Sextant observations aboard the *Carnegie* on her trip to Spitzbergen in 1914. [Even when the vessel is rolling as much as shown in this view it is possible, with the special appliances used, to make good magnetic observations.]

freely through wood, brass, and many other substances, but when a piece of iron or steel is interposed the Earth's magnetic lines of force are displaced or altered to such an extent that a compass

nearby may be seriously affected. So our ship is itself a magnetic body, and our standard compass points in the direction as determined by both the Earth-magnet and the ship-magnet.

Unhappily, also, the ship's magnetism varies both in direction and strength as our vessel travels from port to port; it varies with the course, and with the buffeting of the waves against the ship's sides. The skilled mariner must be ever on the alert and must know how to reduce the errors of his compass to the smallest amount possible, in other words, apply correcting or compensating devices, and then constantly control the outstanding error by observation. To do all of this successfully, he must first know what direction the compass would point were his ship not a magnet. As he can not reconstruct his vessel, he must instead have a chart which will show him for every place over the oceans traversed what the correct compass direction is. The securing of the data for such a chart is the special object of the vessel of which many of you have already heard. This illustration must serve, for time is fleeting, to bring home to you at least one of the objects of magnetic surveys.

The idea of making such a magnetic survey of the Earth is not a new one, but never before has it been possible to accomplish it on the scale and within the time that the work is being done under the auspices of the Carnegie Institution of Washington. After the initial work in the Pacific Ocean, 1905–1908, on the chartered vessel the *Galilee*, it was decided to construct a vessel specially adapted for ocean magnetic surveys—a non-magnetic ship.

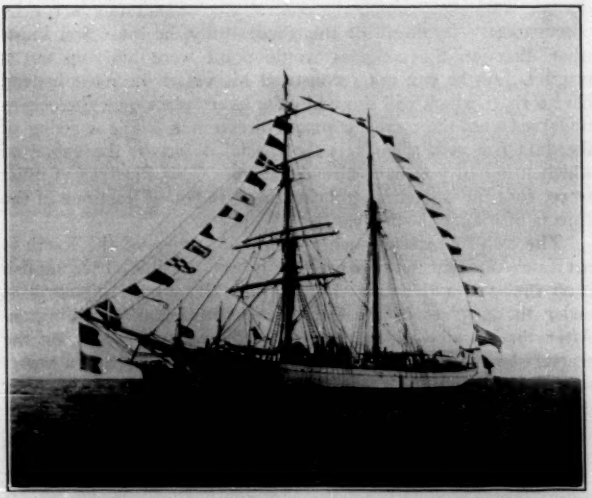
THE "CARNEGIE."

And thus we come now to a brief recital of the work of the non-magnetic yacht, the *Carnegie*, a picture of which you see on the screen (Fig. 6). Note her graceful lines and sturdy appearance! Having weathered many a severe gale, this vessel is possibly the best known craft afloat; if not, she is certainly, as one of our magazines has declared, the most *unattractive* one. Her length is but 155 feet over all, her beam is 33 feet, her tonnage is less than one-hundredth of that of the modern ocean greyhound, yet she has achieved a record during the six years of her existence of which her owners—the Carnegie Institution of Washington—are proud. Her voyages have extended from the parallel of 80°

north, off the northwest coast of Spitzbergen, to New Zealand. She has travelled the " seven seas " and has encompassed the Earth seven times, with scarce a mishap and no loss of human life by accident or negligence. It would seem that it is safer to bunk aboard the *Carnegie,* in one of her cosy, non-magnetic beds, than to repose in magnetic slumber in the most comfortable bed ashore!

The *Carnegie* is built of wood, bronze-fastened, and is rigged

FIG. 6.



The *Carnegie* at Bahia, Brasil, in May, 1913, dressed in honor of the port holiday. [One of the two special observing domes is seen just abaft the foremast.]

with hemp, all metal work on the spars being of bronze and gun-metal. Even the anchors, of which there are four, aggregating 5500 pounds, are of bronze. The usual chain cables are replaced by hemp, as was the common practice some hundred years ago. To carry out the idea of a non-magnetic ship, we had to revert to old practice in some other details. For example, a fisherman's windlass, of a type still seen on fishing schooners, is used to weigh

anchor by a pumping action. The cooking ranges and refrigerating plant are of bronze and copper, and the cutlery is of Mexican silver.

The only iron and steel on this unique vessel is that entering into certain parts, the pistons and cams chiefly, of the auxiliary power, a producer gas engine. But the total mass of the magnetic material is only about 600 pounds, or 3 per cent. of the total weight of the power plant. Its distance from the nearest instru-

FIG. 7.

The personnel of the *Carnegie* usually consists of the commander, who is in charge both of the observational work and of the vessel; 4 observers, 1 clerk, 3 watch officers, 1 engineer, 1 mechanic, 8 seamen, 2 cooks, and 2 cabin boys—23 persons in all. [The after dome, or observatory, is shown on the left.]

ment used in the magnetic observations is such as to cause no observable effect.

Among the special features are two revolvable glass domes (see Figs. 6 and 7) which form the observatories in which the magnetic observations are made, the observers (Fig. 7) and instruments being thus completely sheltered from wind and weather. In addition to the magnetic work, observations are made in

atmospheric electricity, and also for the determination of the amount of atmospheric refraction.

The *Carnegie's* speed is, in general, a leisurely one in comparison to that of a modern liner, about 100 to 150 miles a day, this being the average distance apart of our magnetic observations. Still, with a fair wind about 200 to 300 miles may be the *Carnegie's* daily run. The passage from St. Johns, Newfoundland, to Falmouth, England, in 1909, was made in eleven days. The *Carnegie* rides the boisterous waves up and down like a duck, instead of butting through them as does the ocean greyhound; she may thus have dry decks when the larger vessel is being continually drenched.

Let me then invite you to take a trip on the *Carnegie* from New York to Colon, next through the Panama Canal to the Pacific Coast, so that by personal observation you may become familiar with her work and her personnel.*

ERRORS OF MAGNETIC CHARTS.

A word as to the errors found in the magnetic charts heretofore in use for navigational purposes and scientific investigations. In the Pacific and Indian Oceans, where reliable information was especially scanty until the magnetic data of the Carnegie Institution of Washington were obtained, the errors in the compass direction, as given on the mariners' charts, were from 1° to 5°. The errors, unfortunately, were frequently in the same direction for stretches of 1000 miles and more. Thus, for example, on the 2000-mile run from San Francisco to Honolulu, the effect of the compass-chart errors, averaging from 1° to 2° always in the same direction, was to set the ship's course ever to the northward of that intended. Thus the vessel at the end of a week's voyage, during a cloudy spell, when the course could not be controlled by Sun or stars, might be found about thirty miles to the north of her intended landfall.

Matters were even worse on the run from Colombo, Ceylon, to Mauritius, in the Indian Ocean, where the compass-chart errors reached 6°. Peculiar experiences had been reported at various times with regard to the apparently rapidly-changing magnetic

* Here motion pictures were shown, as taken on the *Carnegie's* 1915 cruise, from Brooklyn to Balboa, Canal Zone.

deviations, or ship's magnetism, during this passage. The *Carnegie* observations of 1911 showed that it was not rapidly-changing magnetism of the modern steel ship that was the cause of these peculiar experiences, but the systematic and cumulative errors made in basing the ship's courses on the charts then in use.

Similar errors, though not quite so large, for the Atlantic Ocean, were disclosed on the *Carnegie's* trip from Brooklyn to Falmouth, England, in 1909. There had been repeated reports by reliable navigators that some peculiarity existed off Cape Race, Newfoundland, which caused an abrupt change in the ship's magnetic deviations. It was shown indisputably by the *Carnegie* observations that the fault was to be ascribed not to any pronounced peculiar magnetic conditions in the ocean, off Cape Race, but to the peculiar distribution of the errors of the mariners' magnetic variation charts. The chart errors were of opposite sign on the two parts of the voyage, New York to Cape Race, and Cape Race to the English Channel. The effect was always to set the ship's course towards the rock-bound Newfoundland coast, no matter whether the ship came from the east or from the west.

Errors in the magnetic dip charts have been found as great as 6.5°, and in the charts giving the strength of the magnetic force acting on a compass needle as great as one-tenth of the quantity.

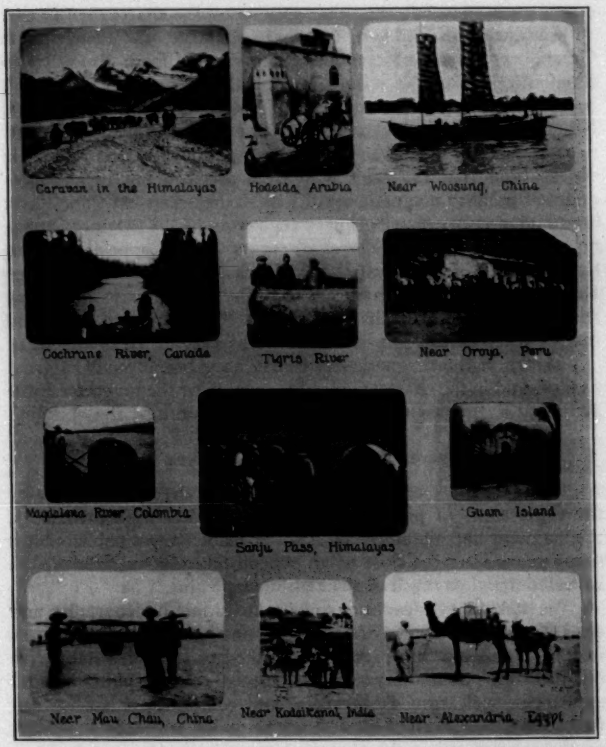
PROMPTNESS OF PUBLISHING DATA.

From the start of our work it has been the aim to profit by the experiences of previous expeditions. Well-nigh invariably, the magnetic data obtained could not be made known publicly until many years after the close of an expedition. By such delays the collected data lost much of their utilitarian value.

We therefore endeavor to supply the leading hydrographic and scientific establishments of various countries promptly with our results. This aim has been accomplished to such an extent with our facilities—a non-magnetic ship, specially-devised instrumental appliances, well-trained observers, and computers—that we can furnish the data of chief interest in navigation within two months, on the average, after the observations were made at sea. Thus the results of the observations for compass direction obtained on the *Carnegie* on her passage in July, 1915, from Honolulu to Dutch Harbor, Alaska, were received at the Office of the Depart-

ment in time to be sent out to the chief hydrographic offices engaged in the construction of magnetic charts by the end of August,

FIG. 8.



Typical views of land magnetic survey expeditions in various regions of the Earth.

1915—hence, in this instance, but one month after the close of the series of observations.

LAND SURVEYS AND STATUS OF MAGNETIC SURVEY OF THE EARTH.

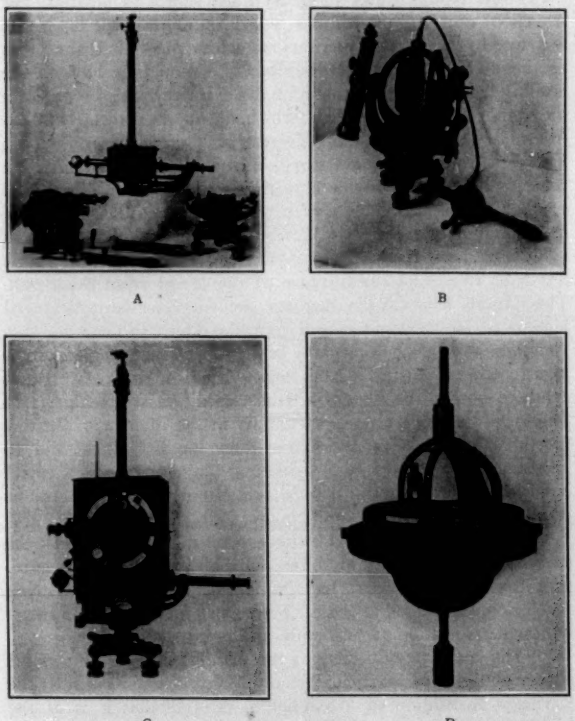
A few typical views (Fig. 8) must suffice to illustrate the travels of our land expeditions, which, in many respects, are no less worthy as regards meritorious achievement than the work of the unique vessel just described. We might easily fill the evening with a recital of some of the experiences encountered in the course of these expeditions, which, during the eleven years' existence of the Department of Terrestrial Magnetism, 1904–1915, have penetrated nearly every region of the globe, and have been achievements in geographic exploration as well as in our special science. There have been fifty of these expeditions in about one hundred and twenty different countries. Fully a million miles have been traversed, or a distance forty times around the Earth or five times the distance of the Moon from the Earth. The stations at which the magnetic elements have been measured number about 3300 and extend from the Arctic to the Antarctic. Among notable expeditions may be mentioned the complete crossings of China, Australia, and South America, east to west and south to north; the Trans-Saharan expedition from Algeria to Nigeria; extensive canoe expeditions in the interior of British North America to more or less unexplored regions, and to Hudson Bay; hazardous coastal trips in Africa and Central America; difficult interior trips in Asia Minor, Persia, and various countries of Africa and South America, etc.

It is pleasing to note here the interest taken in the work the world over, as evidenced by the cordial coöperation received in return for that extended to foreign nations. Thus the following resolution was passed at the St. Petersburg meeting of the International Association of Academies in May, 1913:

"The committee, in view of the work of making a magnetic survey of the globe, particularly on the oceans, undertaken by the Carnegie Institution of Washington, resolves that it is of the highest importance that similar work be completed as soon as possible, in those countries where no surveys exist or where they have been made at epochs relatively distant from those of the Carnegie Institution of Washington.

The next slide (see map) exhibits the status of the magnetic work of the Carnegie Institution of Washington on land and ocean, from 1905 almost to the close of 1915; as you see, it shows the large extent of work accomplished. Nearly all parts of the

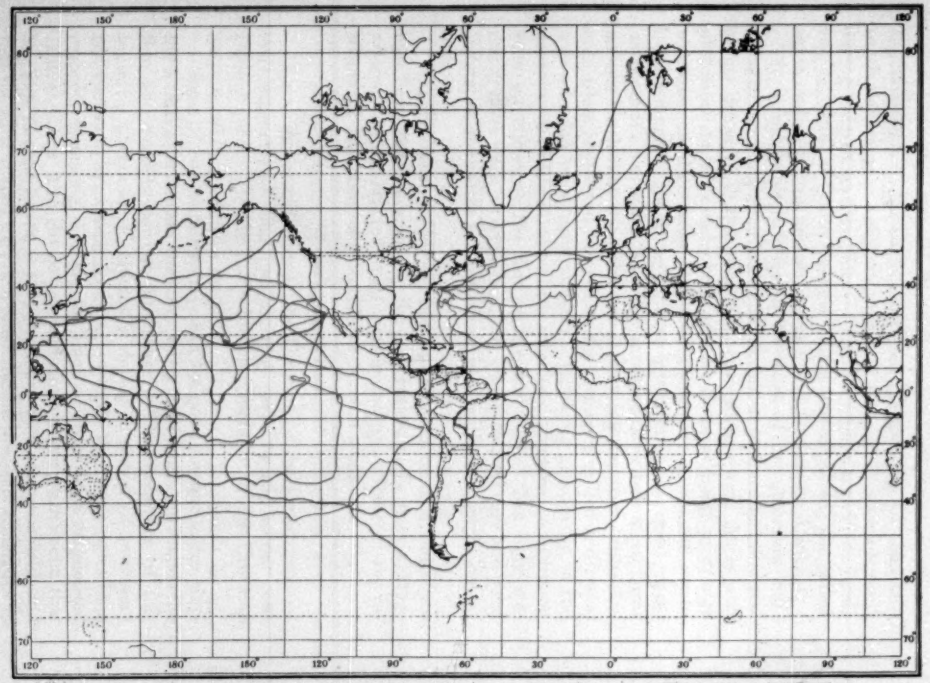
FIG. 9.



A B C D

Views of some of the instruments used in magnetic survey work, designed and constructed by the Department of Terrestrial Magnetism. A. Magnetometer-inductor. B. Earth inductor used both on land and at sea for measuring the magnetic dip. C. Universal magnetic instrument for measuring all the magnetic elements and for the determination of geographic position; especially designed for difficult land expeditions requiring a light and compact type of instrument. D. Deflector used on the *Carnegie* for measuring the horizontal intensity of the Earth's magnetic force, and the magnetic declination.

Earth have now been covered with magnetic surveys. On December 6, 1915, the *Carnegie*, as in 1914, under the command of Captain J. P. Ault, left Port Lyttelton, New Zealand, for a cir-



THE MAGNETIC WORK OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM, 1905–15 [NOVEMBER

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cumnavigation of the regions between the parallels 50° and 60° south, where practically no magnetic data have been obtained during the past seventy years. [The *Carnegie's* arrival on January 12, 1916, at South Georgia Island was reported; she sailed again on January 14, and arrived at Port Lyttelton on April 1.]

It is impossible to refer to the work of the observers individually in calling attention to the devotion, zeal, enthusiasm, and ability displayed in the successful accomplishment of duties well performed, at times under most adverse circumstances; in strange countries, amidst strange people with strange customs and speaking a strange language; often over infrequently traversed roads, and even at times in regions either rarely or never before, so far as known, reached by the white man; pursuing the work faithfully, even when revolution was rife in the countries visited and travel was attended with many dangers; following steadfastly in the direction of their goal at no little sacrifice of personal comfort and even sometimes at the risk of life and limb. Not only was meritorious work accomplished, but, owing to their care and good judgment, the entire work was executed without a single loss of life.

The instruments (Fig. 9) used in the work on land and at sea have been largely designed by the Department of Terrestrial Magnetism, and constructed in its own workshop. Some of the instruments have been duplicated for foreign countries.

ASTROMAGNETISM.

I was introduced once as the Director of the Department of Astromagnetism. This incident may serve to lead to our concluding query: Is the Earth the only member of the Universe surrounded by a magnetic field?

Some of you doubtless have had the good fortune to see, during a total solar eclipse, the soft, pearly light which surrounds the Sun and extends far out into space. The streamers of this beautiful phenomenon, especially during a period of minimum sun-spot activity, appear to curve towards the Sun's poles in a manner resembling strongly the lines of force of a magnetized sphere. Now it might be inferred from these phenomena that the Sun, like the Earth, is also enveloped by a magnetic field, and that the solar corona may be a phenomenon precisely analogous to our polar lights.

In fact, recent observations made under the direction of George E. Hale, Director of the Solar Observatory of the Carnegie Institution of Washington, definitely proved that the Sun is, indeed, a magnet, or at least acts like one. Hale also found that the polarity of the magnetic field of the Sun is the same as that of the Earth's magnetic field. That is to say, the Sun's north magnetic pole is near the Sun's true north pole, just as the Earth's north magnetic pole is in the region of the Earth's true north pole.

If the Sun possesses a magnetic field in spite of its high temperature, about 12,000° F., at which no magnetism as exhibited by permanent magnets could exist, what agency is essential for the production of a magnetic field? The question has been raised as to whether every large rotating mass may not be a magnet.[1] If so, picture to yourselves orbs innumerable spinning through space, "clothed, as it were, in gossamer garments woven of lines of magnetic force," pulsating, vibrating, ever interacting and responding to each other's external influences.

Our magnetic observations are registering daily by a photographic process mysterious messages—a kind of handwriting on the wall, as it were, which perhaps some day we may be able to decipher. "On that (photographic) paper," as Clerk Maxwell well said, "the never-resting heart of the Earth traces, in telegraphic symbols, the record of its pulsations, and also the slow but mighty workings of the changes which warn us not to suppose that the inner history of our planet is ended."

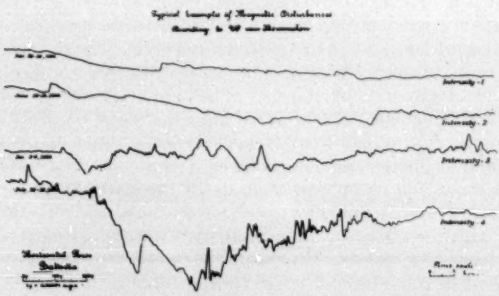
Listen to the receiver of a wireless station. Instead of hear-

[1] Among the various ways by which a magnetic field could be produced during rotation of a body is the following: Electricity in motion is equivalent to an electric current, which in turn is accompanied by a magnetic field. If, then, the Earth is electrically charged, effects will arise, during its rotation, similar to those of a magnetic field. We know electricity to be an essential constituent of all matter. Suppose that while the total positive charge within the Earth is equal to the total negative charge, the volume or sphere within which it is contained is slightly less than that assumed to contain the negative charge. In other words, suppose, because of some action, the volume density of the positive charge is a trifle larger than that of the negative charge. Then during the Earth's rotation magnetic effects will ensue similar to those actually observed. If the radius of the sphere assumed to contain the total negative charge exceeds the radius of the sphere containing the positive charge by 0.2×10^{-8} cm., or 0.02 of the radius of an ordinary molecule, or one forty-millionth of the thickness of ordinary writing paper, a magnetic field of the required strength will be produced during the Earth's rotation.

ing distinct, sharp messages, you are confused by a continual crack, crack, crack, resembling distant musketry. You are told that these extra and ever-occurring signals are the so-called "electric strays"—God's voice, as Professor Pupin recently said.

In the same way the picture (Fig. 10), which you now see of these magnetic curves, may contain the printed record of mighty cosmic events, the full import of which is at present a sealed book to us. Thus through the Earth's "electric pulse," and through its "magnetic pulse," strange things come to our knowledge. A truly prophetic vision must have been that of Orpheus, who declared, "With the lodestone, you can hear the voices of the gods, and learn the mysterious things of heaven."

FIG. 10.



Specimens of curves showing fluctuations in the Earth's magnetism as registered photographically at magnetic observatories.

Suppose that we do ultimately find every rotating mass to be a magnet, the next question cosmical magnetism asks is, Which is effect and which is cause? In other words, are the magnetic fields, which we find associated with the Earth and the Sun, caused by the rotation of these bodies, or is their rotation to be referred in some manner to preëxisting magnetic fields? Is it a mere coincidence that the direction of rotation of nearly all the planets and the direction of revolution around the Sun of all of them are the same as the direction of the Sun's rotation?

It is an interesting fact that Gilbert advanced his theory that the "Earth is a great magnet" largely to account thus for the Earth's rotation. To him the Earth was but a great, round lode-

stone. It had poles and an equator, just as the small magnetized globe, "earthkin or terrella," as it was called, with which he carried out his experiments, had its magnetic poles and its magnetic equator. Just as the terrella behaved with reference to the Earth, so did the latter with regard to universal space, and thus remained "constant in a fixed direction in the universe." Furthermore, the Earth turned on its axis just as the terrella did on its axis when floated in a bowl of water and brought under the influence of the Earth's magnetic force. He thought that the Earth's magnetic poles were coincident with its poles of rotation, and so it was natural, perhaps, that he should speculate "on the magnetick diurnal revolution of the Earth's globe," and ascribe it to some action in space.

It is a striking circumstance that the most noted astronomers to-day are seeking help from the student of magnetism in the solution of some of their problems respecting certain outstanding irregularities in celestial motions which cannot be explained merely by gravitational forces. They are even now postulating cosmical magnetic effects, in addition to those resulting from gravitation. Indeed, it is the ever-increasing belief that gravitation and magnetism are closely allied.

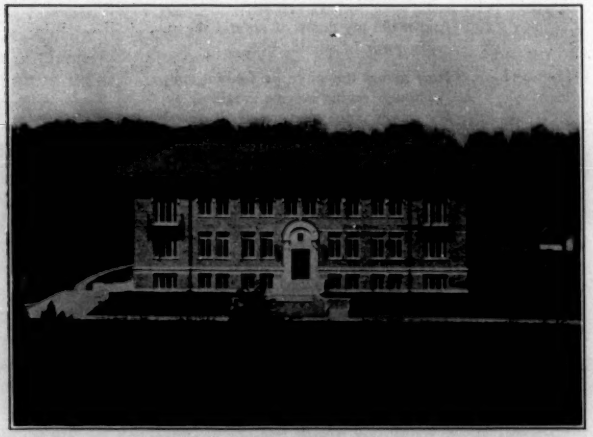
Here it will be of interest to quote Benjamin Franklin, who expressed himself thus:

"Has the question, How came the Earth by its magnetism? ever been considered? Is it likely that *iron ore* immediately existed when this globe was first formed, or may it not rather be supposed a gradual production of time? If the Earth is at present magnetical in virtue of the masses of iron ore contained in it, might not some ages pass before it had magnetic polarity? Since iron ore may exist without that polarity, and by being placed in certain circumstances may obtain it from an external cause, is it not possible that the Earth received its magnetism from some such cause? In short, may not a magnetic power exist throughout our system, perhaps through all systems, so that if men could make a voyage in the starry regions, a compass might be of use? And may not such universal magnetism, with its uniform direction, be serviceable in keeping the diurnal revolution of a planet more steady to the same axis?"

We thus see that the problems of the Earth's magnetism, or the answer to our question, "What is a magnet?" lead to the

very outer boundaries of human knowledge. When asked to what end we are studying and mapping out the magnetic state of our planet, we instinctively recall that well-known query, "What is the good of a new-born babe?" Can any one foretell the result of investigations the prime object of which is to learn how Nature carries out her experiments on a scale of magnitude far beyond the reach of any laboratory experiment that Man can devise?

FIG. 11.



The laboratory and headquarters of the Department of Terrestrial Magnetism at Washington, D. C.

CONCLUSION.

Says Schuster: "Atmospheric electricity and terrestrial magnetism, treated too long as isolated phenomena, may give us hints on hitherto unknown properties of matter."

Great problems then await solution. It is hoped that some of them will be solved in this Laboratory—the home of the Department of Terrestrial Magnetism (see Fig. 11).

But the hour has struck, I have "run my compass," and must dispense with further argument and illustration. I have attempted to show throughout the lecture that an inseparable bond unites the search for the beautiful with the achievement of the useful.

I cannot better sum up the common aims of science and humanity, so far as they may be exemplified by the subject of this lecture, than to recite Charles R. Clarke's beautiful lines on the compass:

Ho, burnish well, ye cunning hands!
A palace home for me,
For I would ride in regal state
Across the briny sea.
Bring ivory from the Indian main
To pave my mystic floor,
And make my dome of crystal sheen,
My walls of shining ore.

Now mount the wave, ye fearful ones,
Though raging storms assail,
My sparry lance o'ercometh all—
My strength will never fail.
The storm fiend wraps his murky clouds
Around your trembling sight,
And I can pierce that gloomy veil,
And soar beyond the night.

The lone enchantress of the deep,
I rule its boist'rous realm;
Watch ye my lithe and quiv'ring wand
To guide your straining helm.
Aye, bend your anxious gaze on me;
The polar star is dim,
And driven darkness is awake
With ocean's awful hymn!

For I commune with spirit forms,
Within my wizard cell,
And mantling midnight melts before
The magic of my spell.
By many long, enduring links
I clasp the northern star—
And on the wiry-shadowed chain
I visit her afar.

And sapient eyes have watched me long,
And science has grown gray,
And still ye dream not how nor why
I keep my wondrous way.
Ye know me as you know the storm
That heaps your heaving path,
Ye love me, though, since mine is not
The mystery of wrath!

THE TRANSMISSIBILITY OF DISEASES, AND THE PUBLIC HEALTH.*

BY

ALEXANDER CREVER ABBOTT, M.D., Sc.D., Dr.P.H.,

Director, Laboratory of Hygiene, University of Pennsylvania, Philadelphia, Pa.

AMONG the writings and in the discussions upon vital statistics, one constantly encounters the expression "Deaths from preventable diseases." The uninitiated may properly inquire what are the "preventable" diseases, and what is the justification for so designating them.

If one examine the mortality returns for any or all of our larger centres of population, one notices that they may be classified, roughly speaking, into two approximately equal groups; the one comprising those from non-preventable causes, the other those from causes more or less controllable. For instance, in the annual report of the Bureau of Health of this city for the year 1914 one finds the deaths in the former group bear the relation to those in the latter group, roughly, that 10 does to 8. In the first group are comprised deaths from those manifold degenerations arising within the living body; due in some instances to disturbances of physiological functions peculiar to the individual; in others to constitutional or tissue defects referable to hereditary taints; in others to the destructive influences of vicious habits in eating, drinking, or exercise; in others to the wearing out of the human machinery coincident with old age, and in others to the inability of a new and imperfect organization to meet the strain incidental to the beginning of normal life, as in infancy.

Throughout this group we find that disease and death result from causes operating upon the individual and having but little, if any, influence upon the health of the community at large. While this class is usually denominated the "non-preventable" diseases, theoretically, through attention to breeding, education, and personal habits, the influences of their underlying causes should be lessened and their effects postponed.

* Presented at the stated meeting of the Institute held Wednesday, December 15, 1915.

In the second group, however, we encounter a very great variety of diseases that may be regarded as dependent upon environmental influences; that is to say, their occurrence depends upon the action upon the tissues of agents that in one way or another are associated with the conditions under which we live, or to which we may have been exposed.

As we look further into this second group, utilizing modern knowledge and methods, we discover that in all cases the diseases from which the deaths resulted are the outcome of the invasion of the body by various kinds of living parasites. In other words, they are infective diseases. We find, furthermore, that from all such diseases the causative parasites escape in a living state in one way or another, retaining their power to reproduce the disease in new hosts to which they may gain access—in other words, we find the infective diseases to be transmissible.

As we become more and more familiar with the manifold modes of transmission and with the means adequate to interrupt it, the belief is becoming general that all diseases known to be transmissible are, *ipso facto*, preventable.

It is important to note that certain diseases now known to be infective and transmissible were formerly regarded as not so, and it may be profitable to pass in brief review the growth of knowledge that has brought about the reversion of opinion and made a proper classification possible.

For instance: One need not revert to a very remote period when the word "miasmatic" was used to designate a group of maladies which were supposed to originate from the breathing of air arising from marshy lands. Such diseases were not believed to have any relationship to other cases of the same disease, but all were supposed to develop from the deleterious action of the mysterious miasm. Malarial fevers and yellow fever may be cited as the most conspicuous illustrations of that conception. It is still a fact that both diseases are usually observed in the neighborhood of marsh lands and low-lying littorals, but our new knowledge has placed in our hands the correct interpretation of the relationship. It is not a gaseous emanation, as was formerly supposed, that excites these diseases, and neither the air of marshes, even most dangerous, nor the water of such marshes has, *per se*, the least influence in exciting the fevers. Three important facts explain the whole matter: *First.*—These fevers are due to the in-

vasion of the body by microscopic parasites having the power to destroy the cells of the blood. In malarial fever this is no longer in question; in yellow fever, while no parasite has as yet been seen, still, all trustworthy circumstantial evidence indicates its presence in the diseased body. *Second.*—That the parasite present in the blood of the diseased person can invade and infect the body of another person, but only through the agency of an intermediary host—a mosquito. *Third.*—That the mosquito is an aquatic animal for a part of its life. At once the miasm matter receives full and adequate interpretation. This information is of such obvious, fundamental importance in the prevention of marsh fevers as to require no further discussion. It is of importance to note, however, though we are still in complete ignorance of the specific parasite of yellow fever, we know that the disease is spread and how it is spread, and by destroying the agents concerned in its dissemination it is abundantly demonstrated that the disease may practically be eliminated.

Up to the late eighties there were still teachers of great importance who did not believe that the germ of typhoid fever was capable of producing infection if transferred directly from the sick to the well.

Von Pettenkofer—sometimes known as the father of modern hygiene—died with that belief firmly fixed in his mind. In his opinion, infective parasites—especially such as the germs of typhoid fever and of Asiatic cholera—required to be influenced by the soil before they became dangerous. The rise and fall of the soil water developed a condition, designated by him as "hypothetical x," to which the germs had to be exposed before they were capable of reinfecting. A few thought that the late summer and early autumnal occurrence of this disease was in one way or another referable to the death and decay of vegetation. Our modern conceptions are altogether different: we know that the intestinal infections—typhoid fever, Asiatic cholera, and dysentery—are due to the actions of living germs that may be, and very frequently are, transmitted in a variety of ways, either directly or indirectly, from the sick to the well, and that in most such cases new infections occur. We know that such germs, if allowed to gain access to the soil, remain alive for varying lengths of time and retain all their original infectivity. We know that from such polluted soil drinking water may and does become polluted, and is

then a potent agent in disseminating the diseases. We know that there are no mysterious modifications of the characters of these parasites in operation in the soil. We know that foodstuffs, such as milk, vegetables grown on land fertilized with infected night-soil, shell-fish freshened in polluted waters, may from time to time be the means of spreading the disease. We know that convalescents from all the diseases of this group may serve to originate serious outbreaks, and an abundance of evidence points to the frequent direct infection of those in attendance upon the sick through the simple process of personal contact.

In other words, we are dealing here with three serious infections of the intestinal tract. With every discharge from the bowels, living germs, capable of infecting others, are evacuated in enormous numbers. These diseases are known to be transmissible, and are so obviously preventable by appropriate methods that the widespread existence of one of them—typhoid fever—constitutes a serious commentary upon our intelligence and often upon our integrity.

For about a hundred years we have been aware of the existence of a specific disease commonly seen in the throat: to-day we know it as diphtheria—formerly it was known as "putrid sore throat," "angina suffocative," etc. For most of the time it was hopelessly confused with croup and with the sore throat common to scarlet fever. Since the early eighties, when its exciting cause was discovered, our knowledge upon it has progressed with such leaps and bounds that probably there is no disease over which we could have such complete control, were it possible to secure the necessary coöperation. All mystery concerning its origin and spread is cleared away: we know it results from the activities of a definite, easily recognizable parasite; that the parasite remains on the diseased tissues during the course of the disease and in a living infective condition for varying lengths of time after all constitutional signs of the disease have disappeared; that the parasite may be passed in manifold ways from the sick or the convalescent to those coming in contact, but, as will be shown presently, with the discovery of the parasite and an acquaintance with its life processes, means have been discovered by which not only the sick may be cured, but the well fully protected from the invasion of the germ.

Probably no more important medical discovery was ever made

that that tuberculosis is an infective disease due to a living parasite that may be passed from the sick to the well. Doubtless there are in this audience persons who recall the time, not very remote, when heredity was regarded as the great and all-important factor in the spread of consumption. What a handicap! Can you conceive of greater discouragement than to start in life with the firm conviction that because a parent, a brother, or sister, or another near blood relative had died of consumption, the disease was "in the family," and that you yourself were doomed to fall a victim, often at the time when one should be in the very prime of life? Yet not many years ago, hundreds—yes, thousands—attempted life with that thought constantly before them. What are our views to-day? We still know that tuberculosis may occur more frequently in some families than in others, but we believe its existence due to causes other than heredity, and perhaps of far more significance in perpetuating the disease. The main point is, however, that while a constitutional or tissue condition of relatively low resistance may be transmitted by heredity, strictly speaking, the actual disease is not so passed along, and it is important to note that such lowly resisting constitutions may often be very much strengthened by the practice of ordinary methods of personal hygiene. As in the case of all infections, the germ of tuberculosis may leave the body in a living, infective condition and may produce the disease wherever it finds suitable soil; *i.e.*, tissue conditions suitable for its growth. Studies upon the various manifestations of tuberculosis have acquainted us with the manifold ways by which the parasite escapes from the diseased body and the portals through which it may gain access to the well. All this is without mystery—all this is information of such a character that it can readily be presented to the lay mind in a comprehensible way; and, if there is one factor more than another that is operating toward the lessening of the frequency of this disease, it is the continued dissemination of knowledge upon it that has been going on so vigorously during the past few years.

Another striking illustration of fact supplanting fiction is in the matter of lockjaw—tetanus, as it is properly called. We used to believe that the incidence of the disease was influenced by certain conditions of the weather and by certain geologic conditions. Then came the rusty nail as a potent agent for causation, then the toy pistol and the other explosive agents, through which youth

is encouraged to express its patriotism. What are the facts? The facts are that tetanus, or lockjaw, is a bacterial infection; that the bacteria concerned are irregularly distributed in the soil; that they are often found within the intestinal canal of herbivora, and that, as they possess the power of entering a dormant or resistant stage, they may lie in the soil for a long time without losing the property of causing fatal infections when they gain access to wounds. It is the presence in the soil of this organism that explains the occasional action of the rusty nail in causing tetanus; it is its presence in the soil that explains the tetanus sometimes resulting among children with dirty hands from the toy pistol and other gunshot wounds to which dirt gains access; it is its wide distribution that serves to explain some, at least, of the cases of tetanus that develop after vaccination among persons of uncleanly habits. In other words, dirty wounds may always be looked upon with suspicion. It is this knowledge that has led recently to the uniform early use of tetanus antitoxin among soldiers wounded during the present war, with the result that tetanus following upon gunshot wounds has practically ceased.

In medical literature accounts are occasionally given of more or less widespread outbreaks of pneumonia. We know this disease to be caused by a specific parasite that leaves the body in a living state in enormous numbers during the course of the disease. It is not improbable that epidemiological factors not yet clear to us may be effective in favoring the spread of this disease from one person to another.

Cerebrospinal fever, infantile palsy, and influenza, all of which were formerly ascribed to the most diverse and sometimes mysterious influences, are now known to be infections, pure and simple; and that the parasites causing them pass, in different ways, from the diseased and enter the healthy body, thus reproducing the maladies in the bodies so invaded.

Common inflammations, boils, abscesses, child-bed fever, erysipelas, wound infections, and the like have all been found to be infective in nature, and easily prevented by the adoption of simple, common-sense precautions, cleanliness being the most important.

With regard to another group of preventable diseases—measles, scarlet-fever, chicken-pox, whooping cough, and smallpox—our knowledge is far from satisfactory. We do not know definitely what it is that causes them. We know that all are trans-

missible; that at certain stages they are more readily transmitted than at others; that they seem to be contagious in the strict sense of the word; but, as said, knowledge is incomplete.

Measles we know to be most infective during the pre-eruptive stage; therefore, probably its parasite is contained in the secretions from the eyes, nose, and mouth, and is given off during the prodromal stage. But no parasite has been recognized thus far.

Scarlet-fever we believe to be more often transmitted by the secretions from the nose, mouth, and ears than in other ways, though the scales from the skin are also believed to be infective. As in the case of measles, no parasite has been identified as the cause of scarlet-fever.

The same may be said for the other members of this group. Until we possess more information, measures to prevent the spread of these diseases will of necessity be only in part effective.

In the evolution of knowledge upon the transmissible diseases, light was first thrown upon the problems by the utilization of trustworthy bacteriological methods of investigation. Many of the commonest infective diseases were quickly shown to originate with the invasion of the body by bacterial species that were easily identified. This was particularly the case with tuberculosis, typhoid fever, erysipelas and wound infections, diphtheria, cholera, and a large group of infections of domestic animals that are transmissible to man. But the persistent application of such methods to the analysis of other diseases, obviously of an infective nature, did not supply such satisfactory results. In so far as the proved bacterial infections are concerned, it was possible not only to isolate the causative parasite but to cultivate it artificially, and, finally, to reproduce the disease in animals with the remote descendants of the original parasites obtained from the diseased body. For many obviously infective diseases this was not possible. Parasites could be detected by microscopic examination of the tissues and fluids of the diseased body, but no means were available for their cultivation, or their study under artificial environment, and it was only occasionally possible to reproduce the diseases by direct inoculation.

These obstacles were, in part, finally overcome by the discovery that such diseases as malarial fever, yellow fever, relapsing fever, and certain other exotic maladies are due in some cases *positively* to protozoa (*i.e.*, to animal parasites—not bacteria), and

in others *probably* to parasites of the same general nature. The failure to reproduce the disease by transferring the living parasite from the fluids and tissues of the diseased person to the bodies of the susceptible animals suggested the possibility of an intermediary host being essential to the transference.

Sir Ronald Ross made the important demonstration that certain birds in particular parts of the world were infected by an hæmatozoön strikingly like that seen in man during the course of malarial fever, and that such parasites become infective for other birds only after a sojourn in the body of a mosquito, where they undergo phases of development essential to ultimate transference and infectivity. This demonstration, when applied to the study of malarial fever in man, revealed the fact that the disease is transmitted in this, and only in this, way. Similar observations on yellow fever have brought out the same fact. These results at once attracted attention to the possible rôle of insects in the general dissemination of disease. The outcome of investigations in this field has been of the utmost importance. We now know that insects transmit disease in at least two ways: one, by themselves being appropriate hosts for the parasite concerned; the other by acting mechanically as vectors—*i.e.*, as simple carriers of infective particles from infected persons, animals, or matters to other persons, either directly or indirectly, by way of the food or drink.

In those bacterial infections where the exciting bacteria leave the body with the discharges—as is the case in typhoid fever, Asiatic cholera, and dysentery—numerous insects which frequent the places of deposit may, by becoming soiled with the infective matters, carry such infection into the household and deposit it upon a variety of foodstuffs that serve to support the life and multiplication of the parasite.

Other bacterial infections that are more or less confined within the body, as blood-poisoning, bubonic plague, erysipelas, splenic fever, or anthrax, may be spread by biting and blood-sucking insects without the insect either suffering from infection or being, properly speaking, an intermediary host for the development of the parasite.

As a result of this knowledge, we have come to look upon all insects as menaces to the public health, and this is especially true of those insects that suck the blood of man.

It is now established beyond peradventure that various species of mosquito are concerned in disseminating malarial fever, yellow fever, and elephantiasis; that certain flies are concerned in the perpetuation of sleeping-sickness and the trypanosomiases of animals; that ticks and bed-bugs are the intermediary hosts for the parasites of relapsing fever; that the body louse is the means of disseminating typhus fever; that the rat flea is the active spreader of bubonic plague, and that the common house-fly is one of the frequent means by which all intestinal infections are spread.

Not many years ago it was the common opinion that a patient who had suffered from an infective disease was free from danger to others when he had become well enough to leave his bed and get about. Developments of recent times justify the opinion that this is not always the case.

In so far as several important infections are concerned, we know that the convalescent may sometimes be a menace to others for long into the period of convalescence, even into complete recovery of health and usefulness.

These rather rare cases constitute one phase of the "carrier problem," a problem new to the practitioner of preventive medicine and one beset with many embarrassments for those responsible for safeguarding the public health. Not less awkward is the fact that now and then persons are encountered who may not themselves have suffered from an infection to which they may have been exposed, but who have in one way or another received the infective germ upon or in their mucous surfaces, and thus unconsciously they serve for various lengths of time as sources of supply for such parasites to others.

Up to the present we have no practical means of satisfactorily eliminating this danger. The detection alone of carriers—be they among convalescents or those in full vigor—is a task of such magnitude as to make its completion a matter of grave doubt. We can only recognize their existence and warn against too intimate contact with those recovering from acute infections—especially from the intestinal infections, from diphtheria, scarlet-fever, cerebrospinal meningitis, pneumonia, and infantile paralysis.

Probably one of the oldest medical riddles, and certainly one of the most interesting, is that in which we are called upon to explain why a person who has recovered from a specific infective

disease is not likely to suffer again from the same disease. It is not astonishing that the endeavor to solve this puzzle has engaged the attention of the most competent philosophers and investigators of all times. It was not, however, until comparatively recently that anything approaching a satisfactory solution has been forthcoming, and even now our information leaves much to be desired.

This is scarcely the place or the time to lay before you the bewildering mass of biological, physical, and chemical details that underlies the opinions held at present upon this subject. It will suffice to say, vague as it may sound, that in the course of a non-fatal attack of an infectious disease the tissues of the body undergo a reaction toward the causative agent of that disease that enables them to protect themselves against a subsequent invasion of the same parasite. In some instances—as in the case of diphtheria and tetanus—this tissue reaction manifests itself by the appearance, within the body, of specific antidotes which, by neutralizing the poisons manufactured by the parasites, counteract the destructive effects of such poisons on the vital organs. As the free poisons elaborated by bacteria are known as "toxins," and as diphtheria and tetanus are typical intoxications, the antidotes manufactured by the tissues of those who recover from such diseases are known as "antitoxins." It is of fundamental importance to note that not only do these antitoxins appear in the body of the person who has recovered, but that by particular methods of procedure their production may be artificially induced in lower animals, and may be carried to a point at which they are present in the blood of the animals in amounts far greater than that ever seen in man. But this is not all. If such animals be now bled, it is found that the antidote may be obtained with the blood, in an unaltered state, so that its neutralizing or antidotal value is preserved and may be demonstrated by so simple a procedure as bringing it and its homologous poison together in a test-tube. Furthermore, if it be injected into the body of a person suffering from infection or intoxication by the homologous parasite or poison, it exhibits again its neutralizing properties; *i.e.*, it cures the disease. Of equal importance is the fact that its injection into the tissues of well persons serves to shield against infection by the corresponding germ, or against intoxication by the specific poison of that germ. Both the curative and preventive values of diphtheria

and tetanus antitoxins are so well known as to require no further debate at this time. They constitute our most important agents in combating these diseases.

In another, larger, group of infections we find free poisons playing much smaller rôles than in the case of diphtheria and tetanus. In this group the protein materials of which the parasites themselves are composed are poisonous, but these probably can not, or do not, exhibit toxic activity until the bacteria are disintegrated within the tissues. Antitoxins, strictly speaking, are of no avail in antagonizing such infections, and they are not found in the blood of those recovering from such infections. In the course of normal, non-fatal infections, as well as by special artificial means for stimulating tissue reactions, there seem to be elaborated by the cells of the body antibodies capable of rendering inert such intracellular poisons as are concerned in this type of infection. Our knowledge here is far less complete and satisfactory than that covering the true toxic infections and their antidotes. Nevertheless, in the course of investigations bearing upon this group we encounter certain cells of the body which appear to possess a scavenging function; *i.e.*, they are wandering cells, having the power to travel about the body, pick up, and digest within themselves such objects as are digestible, among such being invading bacteria. It is of importance to note that, in the main, the efforts used to stimulate tissue reactions that may protect from infections of the type under consideration stimulate, at the same time, in varying degrees, the activities of these scavenging cells and render them more energetic in picking up and destroying invaders.

It is this idea that underlies the very modern practice of vaccinating against bacterial infections, by the injection, into the body, of dead bacteria of the same kind as those causing the infection against which we are operating. The enormous reduction in both morbidity and mortality from typhoid fever that has resulted from vaccination with dead typhoid germs is a striking illustration of what may be accomplished, even though it is not possible to fully explain the mechanism of the reaction. Similarly, in the case of Asiatic cholera, much sickness and many deaths have been prevented by analogous procedure. To what extent the method is generally applicable can not now be determined, but it seems logical at bottom, and with further growth of knowledge may

prove, with appropriate modifications, to be a most valuable adjunct to our armament against certain types of infective maladies.

With the foregoing facts well established, it is clear that logical preventive measures are possible.

As the methods of disposal of human waste had always been of a nature to certainly pollute the soil and waters—and as our knowledge had demonstrated that such waste matters usually contained the living germs of various infective diseases, which germs retain their life and infectivity outside the body for varying lengths of time—it is not surprising that attention to this abuse was one of the first and most important steps in the direction of modern hygiene. The opinion had prevailed that, even though grossly and continuously polluted, both soil and water possessed the power, by natural processes, of quickly rendering inert such pollution. A number of important commissions expressed the belief that this, while true in a way, can not be relied upon as a safeguard against the dissemination of disease. In consequence efforts were made to prevent soil pollution by substituting sewerage systems for cesspools and privy vaults, and to adopt artificial methods for the purification of such drinking water supplies as are of necessity polluted or likely to become so. The outcome of these efforts has been so uniformly concordant in lessening infective diseases, especially those of the intestinal canal, as to justify our placing them in the first rank of public sanitary improvements.

In the meantime many outbreaks of transmissible diseases had been suspected of originating with certain food—milk in particular. It was now possible, by the application of modern methods of investigation, to decide this point. The studies upon milk, of milk-producing animals, and of other domestic animals used as food, have shown that many infections of animals are readily transmissible to man in a variety of ways. This has led to a sanitary control of food-producing animals that is quite as rigid and just as important, as a safeguard, as is that being applied to human beings.

Overcrowding and filth had long been regarded as potent for the dissemination and perpetuation of transmissible diseases. With the development of information upon the essential nature of infection and the ways in which infection is transmitted it is possible to formulate regulations for the elimination of these evils.

Not less important are the results of investigations upon the individual. The old term " vital resistance to disease " has now a definite meaning. It is known that we make our *début* in life endowed by nature with a more or less measurable degree of resistance to the invasion of hurtful parasites. Later investigations have shown that such resistance may be depressed or accentuated according to the way in which we live, and, furthermore, in so far as specific infective diseases are concerned, it may, by artificial means, be increased very greatly over the amount with which nature endows us.

A rational life—meaning by that, fresh air, personal cleanliness, nutritious food, exercise and rest in moderation, and the avoidance of those abuses known to interfere with our well-being—always operates in maintaining our natural resistance to the highest point of efficiency. In so far, however, as specific infections are concerned, these means are never sufficient to guarantee protection. One of the most important of the modern problems in preventive medicine is to discover harmless means whereby such protection may be given the individual.

As stated above, the individual who has recovered from an infectious disease is not likely to experience a second attack—we believe that condition to be due to certain cellular reactions that went on in the body during the course of the primary attack. Experiment has shown that these protective reactions may be induced in animals by artificial means that do no harm whatever to the animal, and in numerous instances in which the method has been tested on man it is found that he, too, may be protected. The cellular reaction results from the stimulating influence of the poisons of the parasite upon those tissue elements for which they have specific affinity. When such stimuli are injected into the animal in such small amounts as never to endanger life, the reaction still occurs and its degree may be accurately estimated. Applying this to man, we find that by vaccination, in a variety of ways, the individual resistance to several dangerous diseases may be so increased that the individual becomes immune. This result we see from vaccination against small-pox—where living virus is employed. We see it in vaccination against typhoid fever, Asiatic cholera, and plague—where dead vaccines are used. In protection from diphtheria by the use of antitoxin we observe a different phenomenon—here the human being is simply the passive

recipient of an antidote that has been manufactured in the body of another animal, in which specific cellular reactions have been induced. We are scarcely more than over the threshold of this important field of activity, yet the results thus far obtained justify the hope and belief that future developments will prove of inestimable service to the cause of preventive medicine.

What can be accomplished in the future is well indicated by that which has been accomplished in the past. Through attention to diet, and ordinary conditions of cleanliness, scurvy, typhus fever, and relapsing fever have been caused practically to disappear. It now seems likely that beriberi and pellagra will be eliminated by dietary measures.

By the adoption of approved, common-sense sanitary precautions, intestinal infections—as indicated by typhoid fever—may be enormously reduced. By faithfully practising that which we know concerning the isolation and care of the acute contagious diseases, their spread may be markedly lessened.

Diphtheria has for most people lost its terrors, and its excessive ravages of times gone by are now only of historic interest.

In malarial and yellow-fever districts safeguards against the mosquito and measures toward its destruction have given almost complete protection.

The common house-fly is not only a nuisance, æsthetically speaking, but is proved to be a serious menace to health under certain circumstances; and there are good grounds for the opinion that any and all insects commensal with man may be, and often are, the active agents in the transmission of disease.

I have touched only upon what I regard as the essentials in this important problem. I have taken pains to rob the subject of all obscure technicalities; to indicate that real knowledge is now available, and to insist that we should demand its application to the solution of the problem in which we are all so deeply interested.

Many fundamental phases of public hygiene are of such simplicity as to lend themselves to teaching in our schools, and it is hoped that some time we may see such teaching in operation.

For the further improvement of conditions it is not necessary for us to wait until more discoveries are made—even though this is desirable in certain directions—nor for new legislation to be enacted, for by the faithful utilization of that which is available, enormous benefits may arise, and that, too, without the discovery of a single new fact or the passage of a single new law.

RECENT PROGRESS IN FLOTATION.*

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I. INTRODUCTION.

ONE of the most marked and revolutionary advances of recent years in the art of concentrating ores is the advent and application of the flotation process. Although the basic and essential principles of flotation had been disclosed by the early work of Haynes, Everson, and the Elmore brothers, it is only within the last decade or so that the process has been a commercial success. Historical considerations point out the fact that the installation of the Delprat process, in 1903, at the Broken Hill Proprietary mine in Australia, was probably the first important commercial application of any flotation process; some other installations were also made at or about the same time. Flotation as practised to-day is the result of the diligent labor of many men, and the present state of development cannot be ascribed to any one individual. In its early stages the flotation process of concentration was decidedly uncertain of success because of certain inherent difficulties which were to be overcome. At present every mill owner in the country is considering its applications. The froth flotation process is markedly efficacious in extracting the mineral sulfides from slimes, and, in the main, is more or less restricted to the treatment of extremely fine material.

In a general way, there are three divisions into which the flotation processes may be separated; namely, (1) film flotation, (2) bulk-oil flotation, and (3) froth flotation. Further, these three classes blend into one another gradually, according to the patents secured for the different processes. Technical distinctions are based on such points as these, viz., acid, neutral, or alkaline pulp solutions; mill temperature or hot solutions; various secondary apparatus employed for the introduction of air or the production of gas bubbles; amounts of oil; and other minor differences almost *ad infinitum*. The more important processes which

* Communicated by the Author.

have so far survived elimination by litigation or other means include the following: Minerals Separation process; Potter-Delprat process; De Bavay process; Callow pneumatic process; Hyde process; Janney process, and the Macquisten tube process; and, further, the preferential processes—Murex, Lyster, and Horwood. These processes have been described at length in the patent literature, in the scientific press, and elsewhere, and further comment would make this writing unnecessarily cumbersome.

Strictly speaking, the subject of flotation naturally falls into two divisions, to wit, legal disputes and technology. Litigation has undoubtedly been the most active, as well as destructive, movement in the field, for the development of the process has been constantly attended with an unwholesome amount of legal differences among the contending interests. Probably there was never a technical achievement so hotly contested in the courts as this one. All these involved disputes have so distinctly retarded progression in this process that, charitably speaking, flotation is to-day in a chaotic state.

Regarding present operations, although there are so many flotation plants at work, there is a decided dearth of available data. In short, actual results have not found their way into the literature devoted to mining and allied subjects, presumably on account of the veil of mystery which is supposed to, and actually does, hang over the process. Practice varies with the locality, and, as a whole, the methods are in no sense standardized. Development at the present time is being retarded on account of certain cases pending in the courts, which involve the Minerals Separation, Ltd., and others. For, with these cases still to be adjudicated, many operators seem to hold that any attempt at development and standardization would be folly, which would incur a certain waste of time and money, should the decision be rendered in what is considered the unfavorable way.

II. PROGRESS IN VARIOUS LOCALITIES.

Australia.

To all intents and purposes Australia is in the van in flotation at present, and has been since the advent of the process. The first important flotation installation was that of the Delprat process, as mentioned in the foregoing; this mill operated successfully from its inception and has continued to do so. The joint Potter-Delprat

process was also applied to the treatment of ore at the Broken Hill Proprietary Block 14 Company's mine in 1903, but ceased operations in 1905; whether this particular plant ever recommenced operations is not known to me. These installations, however, mark the beginning of the remarkable growth in the zinc industry of Australia, which country now produces one-fifth of the world's supply of spelter. The Potter-Delprat process is peculiarly adapted to Broken Hill ores, and this fact is the main reason for its marked success; on other ores it may not be as efficient as some of the other processes.

The Minerals Separation process, licensed by the Minerals Separation, Ltd., and the Minerals Separation American Syndicate, Ltd., was first employed about 1904–05 by the so-called Sulfide Corporation in Australia. In brief, the process then was an adaptation of the Cattermole patent, the principle of operation being the coagulation and sinking of the mineral sulfides with a large amount of oil. The original idea of Cattermole was abandoned in 1905 and true froth flotation adopted. The Minerals Separation process was practised in 1907 at the Central mine at Broken Hill, and has operated successfully to date, producing zinc concentrates. At the same time the Minerals Separation, Ltd., by right of purchase secured a large tailing dump from the Sulfide Corporation; the Minerals Separation process was applied to the concentration of the material, and the mill was an immediate success, producing good concentrates. During this time flotation was subjected to rigid experimentation throughout the Broken Hill district, and the practicability of the process was satisfactorily demonstrated. Minor improvements made from time to time have brought it to its present state of perfection.

It is a noteworthy fact that the introduction of flotation at Broken Hill resulted in the total scrapping of the electric separating machines, all being renounced because the newer process effected an extraction of from ten to twenty per cent. more zinc. Previous to the introduction of the Horwood process, it had been impossible to successfully separate the lead and the zinc in the flotation concentrates into marketable products. Owing to the slimy character of the concentrates delivered by the flotation units, the method of further treatment on tables was an imperfect one; this handling was practised, however, as none other so good was available.

The Zinc Corporation, Ltd.,[1] by reason of extensive experiments with the Horwood process, has definitely adopted it as a preferential method of separating the zinc and lead sulfides in the slime concentrates. Briefly, the Horwood process involves a partial sulfatizing roast of the material to be treated, which coats the lead sulfide particles with $PbSO_4$, while the other sulfides of the ore, zinc, iron, and copper are not so affected. The galena is thus "deadened," and the sphalerite may be floated in the ordinary manner in a Minerals Separation or other flotation machine. According to a report of the Zinc Corporation,[2] the Horwood process is a practical installation at its plant. Figures from the most recent annual statement show that the lead flotation plant treating tailings from other companies' mines and also ore from the Zinc Corporation South Block mine produced 26,567 tons of lead concentrate assaying 64.6 per cent. Pb, 6.45 per cent. Zn, and 9.2 ounces Ag from 141,667 tons of ore assaying 14.4 per cent. Pb, 9.3 per cent. Zn, and 2.6 ounces Ag. The zinc flotation plant for the same period treated 221,620 tons of tailings assaying 13.68 per cent. Zn, 5.93 per cent. Pb, and 6.42 ounces Ag, yielding 63,300 tons of zinc concentrates assaying 43.96 per cent. Zn, 13 per cent. Pb, and 13.91 ounces Ag. Of the original material treated in this latter plant, 169,180 tons were dump tailings and the remainder was from the lead plant mentioned above and the British and Junction mines. The Horwood process plant in the same time yielded 5822 tons of zinc concentrates assaying 48.1 per cent. Zn, 6.80 per cent. Pb, and 16.90 ounces Ag; and 2619 tons of lead concentrates assaying 35.55 per cent. Pb, 14.0 per cent. Zn, and 40.52 ounces Ag. The material treated in the process just mentioned included 6144 tons of zinc slime from the zinc plant and 3169 tons from the accumulated dumps for a return as indicated. The cost of operation of the Horwood plant was 30 cents per ton of ore.

A Minerals Separation plant was started in July of 1911 at the Kyloe Copper mine in New South Wales. The flotation yields a 22.65 per cent. copper concentrate from low-grade ore with an extraction of 86.36 per cent.

[1] *Mining and Engineering World*, Jan. 2, 1915, p. 13.

[2] *Mining and Scientific Press*, July 17, 1915, p. 91.

Experiments[3] made in 1913 at Mt. Morgan, Queensland, resulted first in the erection of a 300 to 400 ton-per-day experimental Minerals Separation unit. The ore contained about 2 per cent. Cu as chalcopyrite and $6 in gold per ton. Tests in the experimental unit were satisfactory, and the erection of a 1000-ton plant followed. The work on this cupriferous gold ore showed that all ore had to pass 60-mesh, or good extraction could not be had; and up to 120-mesh the extraction increased in proportion to the fineness of the grinding.

The Elmore Vacuum Oil process was tried by the Zinc Corporation at Broken Hill and later discarded in favor of the Minerals Separation process. The Elmore Vacuum process is not finding much application to-day; most of the installations are in Europe or the British Isles. The so-called De Bavay process was secured by the Minerals Separation, Ltd., in a merger of interests. The De Bavay process is preëminently fitted for the treatment of sands, the tailings or other products to be floated being first deslimed. It will effectively treat material through 30-mesh and not over 5 to 10 per cent. of slime, which is much coarser than the Minerals Separation process can successfully cope with. For fine material, *i.e.*, slimes, the latter is eminently suited, while the De Bavay process is not so efficient.

Work at the Whim Well in western Australia with the ingenious Murex process demonstrates that this preferential method has potentialities; and its future probably lies in the concentration of cupriferous carbonates or other oxidized ores. Another preferential process which was developed in Australia is the Lyster process, owned by the Minerals Separation, Ltd. This process was worked out in detail at Broken Hill, at the Zinc Corporation plant, and received favorable consideration from that company for some time previous to the present great war.

The importance of Australia to-day is due in great measure to flotation, for in less than a decade Australia has risen to the position of furnishing one-fifth of the world's supply of zinc. No mining camp in the world produces so much zinc as Broken Hill. The first shipment of zinc concentrate in 1903 from that place was 50 tons; in 1911, 470,000 tons of 47 per cent. grade zinc concentrate were produced by flotation methods.

[3] *Mining and Scientific Press*, June 27, 1914, p. 1044.

Arizona.

Flotation has gone forward rapidly in Arizona in the last few years, and there is at present great activity in that state because of recent large installations. A noteworthy flotation plant [4] is that of the Inspiration Copper Company, near Miami, Ariz. At this place there are available some 100,000,000 tons of a 1.63 per cent. copper ore, the copper being mostly in the form of chalcopyrite and containing about 0.20 per cent. copper as silicate and carbonate. A large amount of experimental work was first performed previous to the erection of the present mammoth mill. The Minerals Separation process, Callow process, Towne-Flinn process, a process devised by D. Cole, of Morenci, Ariz., and a so-called Inspiration process were tried. The first Minerals Separation unit was ready for work in December of 1913, but commencement of operations was retarded on account of power failure; this plant was designed for a capacity of 600 tons per day. The Inspiration process was designed by the metallurgists in charge and was intended to embody the best features of the other machines without infringing on any of the patents except those of the Minerals Separation, Ltd. The Inspiration Company is licensed to operate under the patents of the latter. The present new mill [5] has a capacity of 7500 tons daily, and when the entire plant is in operation will have a capacity of some 14,000 to 15,000 tons. In addition, the experimental unit is still operating.

The introduction [6] of the flotation process, together with some minor changes in the mill of the Consolidated Arizona Smelting Company, resulted in an increased copper recovery of 20 per cent. The ore contains 2 per cent. of copper as chalcopyrite, with pyrite in a schistose and quartzitic gangue. The former mill system was necessarily complicated because of the nature of the ore; the chalcopyrite, being of a friable nature, caused heavy losses, but the pyrite was more easily concentrated, as it broke coarsely. Although the same ore, the one from the Blue Bell and De Soto mines, is being worked, the flotation process has ameliorated the heavy losses and is effective where concentration on tables was not. In September, 1915, flotation was responsible for a recovery

[4] *Mining and Scientific Press*, July 3, 1915, p. 7.
[5] *Mining and Engineering World*, Jan. 1, 1916, p. 1.
[6] *Metallurgical and Chemical Engineering*, Dec. 1, 1915, p. 897.

of 240,000 pounds of copper concentrates, about 70 per cent. of the total. This company was among those which first used the Minerals Separation process in the United States. An 11-cell unit with a capacity of 225 tons per day has been installed, and the flotation is consummated in non-acid solutions at mill temperature. The concentrates are not recleaned. The oil combination which was found most effective consists of about two parts of wood creosote to one part of a cheap stove oil (light burning oil). The cost of operation is about 27 cents per ton, of which the oil expense contributes 0.028 cent.

The Magma Copper Company [7] at Superior and the Duquesne Mining and Reduction Company at Duquesne have installed the Callow pneumatic flotation process. The invention of Callow [8] marks one of the most distinct advances ever made in flotation. This process calls for agitation with air in an acid, neutral, or alkaline solution, with oil as selective and frothing agent. At Superior the tailings from the finishing tables receive flotation treatment. There are flotation units in experimental operation at the Copper Queen Consolidated Mining Company's mill at Bisbee. Other flotation plants in Arizona include those of the Ray Consolidated Copper Company at Hayden and the plant at the Old Dominion mine. The flotation work of the Miami Copper Company at Miami has become involved in litigation with the Minerals Separation, Ltd.

Idaho.

Flotation has become an important metallurgical process in the Cœur d'Alenes and elsewhere in Idaho. The Callow pneumatic process was applied to the treatment of ores at the mill of the National Copper Company at Mullan, Idaho, the plant being started April 10, 1914. This was the first Callow plant ever erected and was an instantaneous success. Since that time the pneumatic process has been adopted by nearly all the other mines treating lead and lead-zinc ores in the Cœur d'Alenes, notably the Caledonia, Bunker Hill and Sullivan, Gold Hunter, Morning, Hercules, and others. The plant erected by Callow for the National Copper Company had eight regular rougher cells and two cleaner cells, treating some 500 tons in 24 hours with a consump-

[7] *Mining and Engineering World*, Sept. 11, 1915, p. 405.
[8] *Bull. A. I. M. E.*, Dec., 1915, p. 2321.

tion of as low as 0.13 pound of refined pine oil per ton. The Callow scheme finds favor in the district for the flotation of slimes and fine sand.

The surface tension tube of A. P. S. Macquisten, patented in 1904, was adopted by the Federal Mining and Smelting Company for operation at its Morning mill at Mullan in 1909. The operation at this place had been fairly satisfactory, but, as the capacity of a single cell is low and as the process is not well adapted to the treatment of slime, froth flotation is more to be recommended.

The new plant of the Hunter Mining Company[9] at Mullan, according to recent figures, was destined to pay for itself in about three months' time. Under the old scheme of concentration the mill recovery was only 50 to 60 per cent.; with flotation as an adjunct the mill is recovering 90 per cent. The flotation process at this place consists of nine Callow rougher machines and three cleaners. Four roughers and two cleaner cells were working in March, 1915, producing from 15 to 16 tons of a 50 per cent. lead concentrate from 160 tons of feed. The oil consumption was low, about 0.33 pound per ton.

Montana.

One of the most remarkable and efficient flotation plants in the country is that of the Butte and Superior mill at Butte, Mont., operating on a lead-zinc ore. The early experiments of James M. Hyde, conducted at Basin, Mont., led to the introduction of flotation at the Butte and Superior mill. A 1000-ton-per-day plant is working on the treatment of a zinc middling product as an adjunct to concentration with tables and other mill apparatus. The original recovery was only 60 per cent., but with the flotation end of the scheme operative this has been increased to 91 per cent. and more. This mill now uses the so-called Janney frothing machine, and for that reason the company is involved in legal controversy with the Minerals Separation, Ltd., the latter holding that the Janney cells infringe the Minerals Separation patents. No decision has as yet been rendered.

In this flotation process the pulp passes through agitators and thence to a bank of five flotation machines operating in parallel. The first rough concentrates are recleaned, and also the first tail-

[9] *Mining and Engineering World*, March 6, 1915, p. 460.

ings; a system of *clean and reclean* operates with the production of clean concentrates, a middling product, and tailing; the middling is returned to the system. The 55 flotation machines are supplied by six agitators through a distributing system. The frothing is performed in mill temperature solution with pine oil as the collecting element; copper sulfate and sulfuric acid are also added.

A notable installation, also, is that at the Timber Butte mill,[10] which receives ores from the Clark Elm Orlu property. Analysis of this ore shows 20 per cent. Zn, 1.5 to 2.5 per cent. Pb, 0.8 per cent. Cu, 7 to 8 ounces Ag, and 20 to 80 cents in gold. The mill process is a combination of water concentration and flotation. The coarse flotation concentrates are treated on tables in order to remove the lead and iron and produce a marketable product. Mill slimes from an Akens classifier are settled in a Dorr thickener tank, and the prepared pulp then fed to the flotation units. The flotation process is that licensed by the Minerals Separation, Ltd.; there are 8- and 11-cell machines with 150 tons and 600 tons capacity respectively. Recovery has been as high as 98 per cent. The average daily production consists of 110 tons of zinc concentrates, and also lead concentrates of a 50 per cent. grade carrying considerable silver.

Another plant, in partial operation, is the 800-ton-per-day plant of the East Butte Copper Mining Company. The Janney type of frothing machine is in use for the treatment of second-class ore and dump tailings.

The large plant recently constructed by the Anaconda Copper Mining Company at Anaconda,[11] Mont., is a noteworthy development in this state. The old mill is being remodelled and the flotation process being added to each of the mill sections; each section has a capacity of 2000 tons of feed per day. Each section of the flotation plant has four Minerals Separation machines, 15-cell type; the froth from these machines was cleaned in six Callow pneumatic cells, but the pneumatics have been abandoned and only one clean concentrate is now made. The reagents used in the flotation are: about 6 to 8 pounds of 50° B. sulfuric acid per ton of feed, plus 2 to 3 pounds of kerosene-sludge acid, and 0.5 to 1 pound of

[10] *Mining and Engineering World*, Jan. 1, 1915, p. 29.
[11] *Mining and Scientific Press*, Aug. 28, 1915, p. 312.

wood creosote. Part of the wood creosote is added to the Hardinge grinding mills, and the remainder to the Minerals Separation units. The pulp is heated to about 70° F. The flotation concentrate is thickened in Dorr tanks and dried in Oliver filters.

Utah.

The flotation work in Utah centres about the United States Bureau of Mines and the General Engineering Company in Salt Lake City. The experimental work at the Bureau of Mines, under the direction of Mr. Dorsey A. Lyon, has contributed much to the scientific knowledge and working technic of the process. A new mill has been installed by the Utah Leasing Company [12] at Newhouse, Utah; this is a 500-ton plant, built to treat about 1,000,000 tons of tailings from the Old Cactus mine. The ore is fed to Hardinge pebble mills connected in closed-circuit with Dorr Simplex classifiers; 65-mesh material is treated in the Minerals Separation flotation machines. The oil, most of which is added to the Hardinge mill to get the benefit of the resulting agitation, is a coal-tar creosote—Barrett No. 4—combined with a kerosene acid-sludge from Nicols, Calif.; this oil gave the best results.

Elsewhere.

In California the plant of the Engels Copper Mining Company [13] is operating under Minerals Separation patents and licenses. This plant is interesting, as it is the only one in which no other process than flotation is used. The ore was not amenable to ordinary wet concentration, but is being successfully treated by flotation. A 12-cell Minerals Separation plant with a capacity of 150 to 200 tons per day is producing a 40 per cent. copper concentrate from a mill feed averaging less than 4 per cent. Cu. The flotation feed is of considerable fineness—65 per cent. of it will pass 150-mesh and only 5 per cent. remains on 100-mesh. The oil consumption is low—about 0.4 pound per ton of ore; half of the oil is fed to the tube mill and the remainder to the cells of the frothing machines. The recovery exceeds 84 per cent. The concentrates containing from 10 to 12 per cent. moisture are shipped to the Garfield smelter near Salt Lake City. Another California

[12] *Mining and Scientific Press*, Dec. 11, 1915, p. 889.
[13] *Ibid.*, July 31, 1915, p. 167.

installation is the mill of the Mountain Copper Company at Keswich; this mill is using the Minerals Separation process and has a 250-ton capacity.

That flotation has penetrated the Orient is shown by the plant of the Mitsui Mining Company [14] at its Kamioka mine in Japan. This mine has a yearly output of some 10,000 tons of an ore averaging 10 to 16 per cent. Zn and 3 to 4 ounces Ag. The concentrating plant produces an argentiferous lead concentrate, a zinc concentrate, and a zinc middling; this latter receives treatment by flotation. At this place an acidulated (H_2SO_4) solution is kept at 80° to 85° C., into which a heavy oil is introduced with a pulp ratio of 2 to 1; 29 pounds of 54° B. H_2SO_4 are used per ton. The best recoveries have been obtained on fine material; *i.e.*, 50- and 100-mesh.

The main amount of work with flotation in Nevada has been experimental and has been done at the mill of the Nevada Consolidated Copper Company, embodying mainly the practice of the Inspiration and Ray Consolidated plants already referred to. This work having not progressed further than the experimental stage as yet, no data are available. In New Mexico, flotation processes have been added to the plants of the Chino Copper Company at Hurley, using Janney machines, and at Tyrone, where the Burro Mountain Copper Company has determined the amenability of its slimes with a 500-ton mill and is now constructing a 1000-ton plant. At Chewelah, in Washington, the United Copper Mining Company has a flotation plant in successful operation on slimes.

Flotation [15] has been an active factor in the mining industry of Colorado for a few years, and flotation plants are in operation at such places as the Hudson mill and Newton mill at Idaho Springs, the Sunnyside mill at Eureka, Gold King Leasing Company at Silverton, and others too numerous to mention. In Tennessee, plants are in operation at Ducktown and at the Mascot mill of the American Zinc, Lead, and Smelting Company. This company is about to enter more actively into the field, particularly in Joplin, Mo. A Minerals Separation process has been practised at Britannia Beach, British Columbia, by the Britannia Mining

[14] *Mining and Scientific Press*, Sept. 4, 1915, p. 347.
[15] *Mining and Engineering World*, Jan. 1, 1916, p. 1.

and Smelting Company. The plant of the Braden Copper Company at Sewell, Chile, South America, is an 8-cell Minerals Separation process floating copper sulfide.

III. OILS IN FLOTATION.

The importance of oils [16] in flotation work can scarcely be overestimated, since most or all of the different processes have come to the use of oils. Since almost any kind of oil may be used to effect a separation of the finely-divided sulfides from the gangue, it is not surprising that the number of different oils, which have been tried experimentally and commercially, is almost without end. The present tendency is to determine by trial a suitable oil mixture for a given ore. It is found that coal-tar products are particularly efficacious in the flotation of copper ores, but are not so good for lead and zinc. In the flotation parlance, oils are divided into two kinds; namely, (1) frothing oils and (2) collecting oils. There may be a further classification of each of the above into such types as mineral oils, animal oils, and vegetable oils. One oil in itself may combine both the properties of collecting and frothing, so that at times there may be difficulty in stating whether an oil is a frothing oil or a collecting oil.

1. *Frothing Oils.*—A number of oils have been successful frothing oils, and this includes the pine oils—steam refined and crude—cresylic acid, and turpentines and other pyroligneous products from the distillation of woods. The coal-tar phenols and most or all of the essential oils are efficient frothers. The essential oil of the *Eucalyptus globulus* finds wide application as a flotation oil in Australia on account of low cost; it would be prohibitively costly to use it in this country. Pine oil is unquestionably the best frothing agent known, but has recently become prohibitively costly, and the same is true of cresylic acid. In general, the essential oils give a coherent froth and satisfactory extraction.

2. *Collecting Oils.*—The mineral and tar oils have a marked selective action on the mineral sulfides and are generally poor frothers. The mineral oils used in flotation include crude petroleum, refined oil, gasoline, kerosene, creosol, and coal tar and coal-tar creosotes. Oils derived from the destructive distillation of

[16] *Mining and Scientific Press*, Sept. 25 and Dec. 4, 1915.

wood, such as wood creosotes, pyroligneous acid, and similar products, are good flotation oils from the standpoint of cost and efficiency. Coal tar has the property of stiffening a weak froth, and may be employed as a mixture with 10 per cent. pine oil.

Recent commercial practice demonstrates that acid may be eliminated from the pulp solutions if a suitable oil mixture be determined. The same results can evidently be obtained in an alkaline or neutral pulp as in an acid one. The flotation experts employed in the erection of plants have come to the practice of using, in the work at hand, the oil available. An instance is given where power is generated at a certain plant using Deisel engines, and the practice has become so fixed now that the same oil is used for flotation as is used in the Deisel equipment. Evidently no given oil or combination of oils will perform effective work on all ores; it is a particular problem for each ore to find the most suitable oil mixture.

It is the conviction of at least one large company supplying oils for flotation consumption that there are too many oils on the market, and that a medium-price oil (20 cents per gallon in tank cars) will be the frothing element which large consumers will favor. It is the consensus of opinion that pine products are essential to the production of good froth, and are also good selective oils. Considerable difficulty is experienced by the consumers in the duplication of orders, for it seems as though the oil companies cannot or do not furnish the same oil on repeated orders. Why this condition of affairs should obtain is not apparent.

IV. MISCELLANEOUS CONSIDERATIONS.

The present practice favors the ball mill for grinding the tailings or other material to be floated, as the bulk of the feed is thus reduced to slime, which is the ideal feed for froth flotation. The use of Dorr thickening tanks for thickening the pulp, placed in closed circuit with the grinding mill, seems to be a present tendency for a future standard practice. The fact that flotation can and does work best on slimes has removed the old dread of mill operators for making slimes in the wet concentration; this will result in some minor changes in mill practice. Before shipment to smelter or other market, flotation concentrates must be dewatered by filters to a moisture content of about 8 to 10 per cent.; otherwise, heavy freight bills are incurred which might consume

the profits. The moisture content cannot be too low in the case of long shipments, or heavy dusting losses will take place. The so-called Oliver filter will reduce the moisture to 8 per cent. or less, and is preferable to the pressure type of filter on account of the excessive operating cost of the latter. Filters of this type are employed by the Anaconda Copper Mining Company, the Inspiration Copper Company, the Timber Butte Milling Company, the Federal Mining and Smelting Company, and other large operators.

In smelting flotation concentrates for the recovery of the values therein, the ordinary practice is adhered to, pendent on the nature of the values—zinc, copper, lead, etc. The best practice recommends drying the concentrate before charging into a reverberatory or other furnace; *i.e.*, it is best to charge a hot calcine. If it is desired to reduce the sulfur content, calcines can be made in the ordinary McDougal or Wedge multiple-hearth furnaces.

RESUMÉ.

Generally speaking, the mechanically- or air-agitated machines require fine material for successful performance; *i.e.*, 60-mesh or finer. In other words, most of the flotation processes are preëminently suited to the recovery of slimes. It would seem as though the flotation process should be used as an accessory unit in wet concentration, as an all-sliming plant, with few exceptions, is not an economic possibility in this country. The matter of rougher and cleaner cells is strictly a local consideration and must be determined separately for each individual plant. Two cogent factors enter into the solution of this problem; to wit, richness or leanness of the slime feed and proximity or remoteness from smelters. The dual, *clean and reclean* method, was tried at Anaconda and finally abandoned in favor of the single cleaning method.

In the Callow [17] process the pulp density may vary from 2.5 to 1 on a strictly sand feed up to 7 to 1 on a slimy feed. The particular density of feed is not a matter of such vital importance as is the necessity of a uniform density of pulp supply. In this process the quantity of oil used increases in proportion to the increased volume of pulp, and is independent of the solid content. Hence there is a dictum which says that the pulp should be run as thick as possible so long as other conditions operate satisfactorily.

[17] *Bull. A. I. M. E.*, Dec., 1915, p. 2321.

The advantages of the pneumatic process are: greater recoveries, less oil, greater simplicity of operation, and less skill required to operate. It is known that a pneumatic froth is much more ephemeral than that made in mechanically-agitated machines, and this is an advantage in handling the resulting concentrates.

Universities teaching mining and allied subjects, particularly some of the state institutions in the West, having experimental research bureaus in connection, have taken up the matter of flotation research, as well as the determination of the amenability of ores and mill products, the subject of flotation oils, and other things relative to this process. The present and recently-formed coöperative plan of work among the United States Bureau of Mines, the State Department of Chemical Research of the Kansas State University, and the Mine Experiment Station of the Missouri School of Mines should have considerable bearing on the ultimate solution of some of the present flotation problems. The work at the Kansas Bureau [18] and elsewhere has determined the amenability of the slimes of the Joplin district to flotation, and great savings could be effected were flotation plants installed in that district. The yearly loss in slimes in the Joplin lead-zinc area approximates $11,000,000, which could be saved were flotation plants installed, thus contributing to the resources of the country.

Broadly, flotation has now reached a stage so as to find widespread commercial application. It is a noteworthy fact in the history of milling that such an apparently simple process should have such a ramified development in such a short time. There can be no question that flotation in due time will be a necessary adjunct in all the mills in the mining industry. Already the process has added greatly to the world's wealth. From its inception to date it has produced about $20,000,000 in silver, $1,700,000 in copper, $612,000,000 in spelter, and $19,800,000 in lead.

The Use of X-rays with Intervals of Red Illumination. J. BOYER. (*Scientific American*, vol. cxiv, No. 8, February 19, 1916.) —In the present practice of X-ray surgery, the surgeon, manipulating his instruments under the fluorescent screen, is compelled to work in darkness, although all the while he exposes himself to the harmful effect of the X-rays. On the other hand, the surgeon working in bright light is obliged to depend on an assistant, who, alone in a position to see the X-ray images on the screen, guides him in his

[18] *Metallurgical and Chemical Engineering*, Nov. 15, 1915, p. 847.

work. Because of the drawbacks of both these methods, many surgeons prefer to perform their work without the aid of the X-rays. A new method, worked out by Prof. J. Bergonie, of Bordeaux, France, based on the law of simultaneous contrast of colors, will undoubtedly cause many surgeons to resort to the use of X-rays in their work. The principle involved, originally formulated by Chevreul, is best demonstrated as follows:

If the eyes rest for several moments on an object of a certain shade, after which they are turned away, the eyes retain for a few instants the complementary color of the subject previously observed; this phenomenon being due to the persistence of luminous impression on the retina of the eye. For example, observe for a few moments a red flower and then turn to a disc of white porcelain. The disc will appear to be of greenish tint. As Chevreul has demonstrated, this phenomenon is one of the reasons for the intensification of a color impression when two complementary colors are placed in juxtaposition. Modifying the experiment by taking a disc of greenish shade, it will be observed that the green is intensified by the green impression made on the retina of the eye by the red vision. Likewise, if the eyes are brought to bear on the red flower, its color will be increased by the red impression given to the retina by the green disc. The two colors reciprocally improve each other, and Professor Bergonie has made use of these facts to facilitate the task of the surgeon who, in the course of an operation, utilizes the X-rays to see through the body of his patient.

Professor Bergonie illuminates the operating room by means of an intense red light of great purity, in which there is not a single green or yellow radiation such as are emitted by the fluorescent screen of the X-ray apparatus. Due to the effect of contrast, the sensibility of the retina of the surgeon and his assistants is conserved and even increased during the period of surgical intervention using the red light. Heretofore the employment of normal illumination during intervals has caused not only much eye fatigue to the surgeon and his aids, but has resulted in lengthening operations because of the time necessary to accommodate the retina of the eye to the change. To state the Bergonie method definitely: The active phases of an operation are executed under red light, while the X-ray examination of the patient's body in the region of the operation are made in the greenish light of X-rays for an interval seldom exceeding 30 seconds.

For several months past Professor Bergonie has been applying his method in the hospital of Bordeaux, where it has given much satisfaction. The luminous dome which furnishes the red light is placed directly over the operation table and is of about the same dimensions as the latter in order to avoid shadows. The dome contains 20 lamps of 25 candle-power each, the rays of which pass through red glass. Although the illumination thus furnished is admittedly poor, the surgeons declare it is sufficient for their purpose.

THE PRODUCTION OF LIGHT BY ANIMALS.*

BY

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LIGHT PRODUCTION AS SEEN IN WORMS.

LIGHT production has been reported in the Turbellarian worm, *Typhlophana retusa*, by Viviani, but Mangold regards the observation as not complete, and the case is still doubtful. He takes the same view of Giglioli's report on the lighting of several species of *Sagitta*. The writer feels that both these reports, especially that concerning *Sagitta*, should not be dismissed until a much more careful and wider survey of the field has been made. *Sagitta*, in its habits of a surface pelagic form, is numbered among the animals that are especially liable to illuminate. That the organism possesses a stratified epithelial surface, instead of the simple glandular epithelium of most worms, does not preclude the possibility of its having some kind of light-producing power.

Similar reports concerning a rotifer, *Synchæta baltica*, seem to stand in the same position.

Among the more conventional or higher types of worms we find five chief types of luminosity, the first four of which are polychætes and the last type are oligochætes. These types are:

1. Syllids and terebellids, several members of each with a small amount of rather generally distributed luminous tissue. *Polycirrus auranticus* shows a general luminosity. In *Odontosyllis* these tissues are found to be specialized into definite organs at several points.

2. *Chætopterus*, a form in which the tissues and organs are much more highly organized and specialized.

3. The polynœid worms, in which the majority of the members have a very strong, efficient, and highly-specialized lighting system.

4. *Tomopterus* and its allies. Here there still remains a little doubt as to the lighting power, but the organs in question (some have called them eyes) are highly specialized and in unusual positions.

* Continued from page 556, April issue.

5. Certain oligochætes, as *Lumbricus*, etc., in which light has undoubtedly been seen coming from parts of the body, the only question being if it is really derived from the animal's body or from bacteria or fungi that they have eaten or that are parasitic upon them.

The syllid and terebellid worms and many related forms show the simplest kind of luminosity. The power is almost restricted to those that live in burrows or tubes and whose body is provided with a bunch of ciliated filaments. As examples of the syllid group we will discuss a species of *Polycirrus auranticus* from the coast of England, and then the terebellid form, *Odontosyllis enopla*, in which the light production is more highly specialized and has a known purpose.

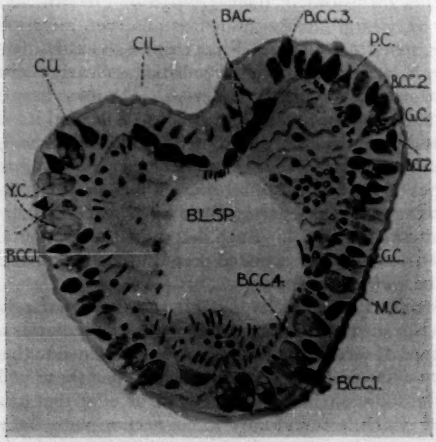
POLYCIRRUS AURANTICUS.

The particular *Polycirrus* which we are describing is a small, thick, red-colored worm living among the rocks and weeds near low-water mark. From its head protrude two large bunches of long, fleshy tentacles. Each tentacle shows in cross-section (Fig. 1) a core of connective tissue and muscle, and contains blood-vessels lying in its entire length. The blood is but little removed from the outside water in which the tentacles lie, and, although the tentacle is not counted as a gill, the exchanges of oxygen and carbon dioxide are effected in the large amount of blood-vessel surface thus exposed. The tentacle also has a ciliated groove by means of which food is collected. The animal lies in its habitat with these tentacles extending out in all directions on the surrounding sea-bottom. The body is blood red and the tentacles are orange in color. It is not eaten by fish on account of a poisonous or distasteful odor emanating from its body. When the animal is disturbed, especially when the tentacles are injured or rubbed in any way, these tentacles show a rather weak violet-blue light which flashes out strongest at the tips of the tentacles and less strong as one looks toward their proximal ends. Practically no light is seen under ordinary conditions in the fourth part of their length nearest the head to which they are attached. When the animal is stimulated in some excessive or extreme manner a weak light may be seen on most of the body for a short time. When the animal is attacked by any fish it curls its body up into a ball and wraps the tentacles around this ball. It is the tentacles that are distasteful to other animals and not the body, if the

tentacles have first been cut off. We can thus see that the light acts in the same way in the darkness as the orange color of the tentacles does in the daytime. It is a warning signal and a protection to its owner.

Looking again at the cross-section as shown in Fig. 1, we see that the outline of the tentacles is not round. One side is deeply indented by a groove which follows the whole length of the struc-

FIG. 1.



Transverse section of one of the tentacles of the worm *Polycirrus aurantiacus*. *cil.*, ciliated cells of feeding groove; *b.c.c.*1, black-capped cells (light-cells); *b.c.c.*2, younger black-capped cells before secretion; *b.c.c.*3, black-capped cell discharging through ruptured cap—cap cut in longitudinal sections; *b.c.c.*4, youngest stage of secretion reservoir in a black-capped cell; *m.c.*, mucous cell; *y.c.*, yellow cells (poison-cells); *g.c.*, granule-cells; *ba.c.*, basal cells (yellow); *cu.*, cuticle; *p.c.*, proximal, large granule-cells; *bl.sp.*, blood-space.

ture from point of origin on the head to tip. All parts of the tentacle are covered by a strong, simple epithelium. In the groove the cells are furnished with well-developed cilia, and the cells are otherwise undifferentiated (Fig. 1, *cil.*). It is evident that we may not look for the source of the light here.

The remainder of the epithelial cells, however, lining the outer sides of the tentacle show several kinds of marked differentiation of their outer cytoplasm. In general they form a row of even

height, covered continuously with a soft, elastic cuticle (Fig. 1, *cu.*). The nuclei lie rather closer than is usual to the proximal ends of the cells and are large, deep staining bodies with a good, strong chromatin pattern. They lie so closely together that if they are all epithelial nuclei the cells must be very narrow and lie closely together. Only a few of the nuclei are shown in the figure. The lateral walls do not show plainly enough to decide the exact width of the cells.

Many of these cells appear to have no distal secretion areas or no secretion inclusions in their cytoplasm. In others, however, there are very large, easily-stained or observed inclusions, which will be discussed as follows: First we find an easily-identified cell containing a large mass of yellow substance, clearly a distal secretion reservoir of some specific material. The mass has the coarse, reticular appearance of many ripe mucous cells, and its distal half shows the richest yellow tint, the proximal edge being almost without this color (Fig. 1, *y.c.*). The nuclei belonging to the different types of cells appear to be of one kind, and it has not seemed possible to associate any particular kind of nucleus with this particular secretion reservoir. Such determination can only be made by means of carefully-dissociated preparations in which the single cells can be viewed alone.

It is evidently these cells that give to the tentacle its orange color. Also, since this color is confined to the tentacles and since no other type of secretory cell appears to be confined to the tentacle, we may assume with considerable safety that these yellow cells also are the source of the offensive taste or odor that protects the worm and which is found only in connection with the tentacles, as Dr. Garstang has shown by his experiments at the Plymouth Zoological Station.

We are now confronted with as many as seven other kinds of cells in this epithelium, some of which types most probably represent different growth or regeneration stages of the same structure. These will be described in an order which, in part, possibly shows these relationships.

The second kind of cell to be described may be termed the gray, black-capped cell, from the appearance of the secretion reservoirs (Fig. 1, *b. c. c.* 1). These reservoirs are distal in the cell, the smaller ones often lying at an unusual angle in the cell (Fig. 1, *b. c. c.* 2). This may, perhaps, be taken to indicate an unripe

stage. The proximal part of the body of this structure is of a homogeneous gray color (Bouin's fixation, iron hæmatoxylin stain). If granular, the granules are so small as to form a homogeneous mass. The distal part is somewhat pointed and stains, in this preparation, a jet black. When full sized, this point rests against the cuticle, and in a certain number of the cells the observer can see a plug of the secretion protruding from a pore in the cuticle, as in Fig. 1, *b. c. c.* 1. These cells, from their abundance and visible discharging activity, appear to the writer to be the light-cells, although lack of opportunity for experimental study leaves the matter in some doubt. An important point in connection with the discharge of this cell is shown at *b. c. c.* 3, where a fortunate cutting of the section shows that, in discharging, the secretion ruptures the black cap at its point; also, that this cap is really a thin cap and not a solid point. From its staining reactions it appears that this cap may be of a muscular nature, although it is almost equally probable that it may be of some inert, connective substance, as of keratin or an allied material.

The third kind of cell, as distinguished by its secretion reservoir, is of a solid black color and nearly always of the same shape as the black-capped cells. Many of these cells are present in Fig. 1, *b. c. c.* 2, and, from their form and position, one must take them to be younger stages of the black-capped cells. Very early stages of the development of the gray, non-staining proximal end were not seen, but some stages of half-and-half were found, and from that up to the large gray cell with a very small black cap. Such an atrophy of a muscular or keratin cap would be an ideal way of retaining the light-secretion until ripe, when a slight pressure by nerve stimulus would discharge the contents in whole or in part. Both the appearance of the cells and the visible evidences of the discharge seem to indicate that the secretion is not all discharged at one time and that it is a rather thick and tenacious material.

The fourth variety of cell seems to be an even earlier stage of development of this same light (?) cell. The secretion bodies that represent this unit appear deep down in the basal part of the epithelium, and as they increase in size they move distally, probably through the cytoplasm of the cell. All stages of this development may be seen in the epithelium, from the small, oval bodies at the base, not larger than the nuclei, through the successively larger bodies up to the third form and, finally, the second sort described

above as the finished light-cell. Fig. 1 shows a number of these bodies, marked *b. c. c.* 4.

We now turn to another kind of cell, a fifth cell in our list, that bears a considerable resemblance to the black-capped cells, except that its secretion reservoir is filled with distinguishable granules. These granules are of medium size, and the secretion bodies are placed distally, with a secretion pore in the cuticle. No discharge masses have been observed and the black cap is missing, although traces of it are visible in a few cases (Fig. 1, *m. c.*). These cells may be mucin cells. The granules hardly indicate this, as real mucin cells usually pass from the granular form of development into the dissolved mucous form before discharge. The probability that they are mucin cells, however, is heightened by the fact that no mucous cells of the usual type are present, and, as in *Lumbricus,* the mucin granules may be thrown out and only turn into mucus after reaching the water. These worms, like most other, seem to have an abundant supply of mucus in life.

A sixth distinct kind of cell shows a large body of secretions extending from the surface almost down to the proximal end (Fig. 1, *g. c.*). This secretion consists of large black granules, well separated from one another and with a few finer ones in between the large ones. But few of these cells occur—one or two in each transverse section. The form, size, and staining reaction of the granules and the elongate shape of the secretion reservoir seem to mark them as a different cell from any other.

The seventh variety of cell is also a coarse, granular one (Fig. 1, *p. c.*). These cells are remarkable for the large size and proximal positions of the secretion organs. Those bodies lie deep in the epithelium, with their proximal ends lying against the basal membrane. The nucleus, in consequence, lies on the side of the secretion body, and this body has the same pear-shaped form that the black-capped cells have, except, perhaps, it is a trifle longer and narrower. The granules are very large and no longer round, owing to their mutual pressure. How this secretion body opens to discharge its content is not apparent, unless the acute point from which the discharge takes place opens into some invisible channel between two cells. Some such arrangement surely must exist, as this is undoubtedly a gland-cell.

But one more kind of gland-cell remains to be described, an eighth variety, that lies flattened out against the basement mem-

brane without any imaginable mode of egress to the exterior for its secretion. The content of this cell is a reticular mass of gray material with a light-yellow tinge. In some cases the gray is very light, when the cells become almost transparent. These cells lie particularly thick under the ciliated epithelium in the groove (Fig. 1, *ba. c.*). They may be cells that elaborate some material that is passed back into the blood, some kind of a ductless gland. It would be hard to prove this with no other evidence than the position of the cells.

Thus we have a number of different sorts of gland-cells in the epithelium of the tentacle of this little worm. It may be easy to do the necessary experimental work to determine the functions of the various kinds, or it may be exceedingly difficult. It would prove an interesting problem in any event.

ODONTOSYLLIS ENOPIA.

This interesting worm was observed at Bermuda by a number of naturalists, who spoke to the writer about it, including Dr. E. L. Mark, Dr. L. R. Cary, Dr. E. Linton, and many others. It was made a particular study of by Dr. T. W. Galloway and Paul S. Welch, who described its habits in regard to the power of light production and thus placed it upon the very small list of luminous organisms the purpose of whose light we understand.

This worm is said never to light except in the breeding season, and then only when in the act of depositing its sperm and eggs. The breeding season occurs in summer time, during the summer months at periods that suggest the lunar month. Thus Galloway and Welch report them in 1904 as occurring at July 4, July 30, and August 23. Possibly they also occurred in early June and in September at the appropriate lunar period. This reminds one of the other worms, especially the various species of Palolo worm, whose reproductive periods are regulated by the phases of the moon. Each of these reproductive periods in *Odontosyllis* also occurred, in a lesser degree, for a day or two before and after the dates named.

The most exact timing of the phenomena, however, takes place with reference to the time of day. While the Palolo spawns at dawn, this worm appears very promptly in the early evening, just as dusk is becoming pronounced. The daily period lasts in each case for only about twenty-five minutes, no worms being seen after

a half hour has elapsed since the beginning of the spawning process. We may well quote Galloway as to the appearance of the process as he observed it:

"In mating, the females, which are clearly swimming at the surface of the water before they begin to be phosphorescent, show first as a dim glow. Quite suddenly she becomes acutely phosphorescent, particularly in the posterior three-fourths of the body, although all the segments seem to be luminous in some degree. At this phase she swims rapidly through the water in small, luminous circles two or more inches in diameter. Around this smaller vivid circle is a halo of phosphorescence, growing dimmer peripherally. This halo of phosphorescence is possibly caused by the escaping eggs, together with whatever body fluids accompany them. At any rate, the phosphorescent effect closely accompanies ovulation, and the eggs continue mildly phosphorescent for a while. The fact that the luminosity is known at no other time is further suggestive that it is produced by the material which escapes from the body cavity. If the phosphorescent glands are external, as the histology of the epidermis at least suggests, the discharge of the glands is closely correlated with ovulation.

"If the male does not appear, this illumination ceases after ten to twenty seconds. In the absence of the male the process may apparently be repeated as often as four or five times by one female, at intervals of ten to thirty seconds. The later intervals are longer than the earlier. Usually, however, the males are sufficiently abundant to make this repetition unnecessary; and the unmated females are rare, if they are out in the open water. One can sometimes locate the drifting female between displays by the persistence of the luminosity of the eggs; but the male is unable to find her in this way.

"The male appears first as a delicate glint of light, possibly as much as ten or fifteen feet from the luminous female. They do not swim at the surface, as do the females, but come obliquely up from the deeper water. They dart directly for the centre of the luminous circle, and they locate the female with remarkable precision when she is in the acute stage of phosphorescence. If, however, she ceases to be actively phosphorescent before he covers the distance, he is uncertain and apparently ceases swimming, as he certainly ceases being luminous, until she becomes phosphorescent again. When her position becomes defined he quickly

approaches her, and they rotate together in somewhat wider circles, scattering eggs and sperm in the water. The period is somewhat longer, on the average, than when the female is rotating alone; but it, too, is of short duration.

"So far as could be observed, the phosphorescent display is not repeated by either individual after mating. Very shortly the worms cease to be luminous and are lost. Often they give the appearance of sinking out of sight; however, this appearance is negatived by the fact that I have caught both sexes at once by timing the current and dipping down stream as much as six or eight feet from the point of latest visible phosphorescence. Sometimes as many as two or three males seem to take part in one mating.

"The females caught and examined immediately on becoming luminous are full of eggs. Those caught after three or four displays, or after copulation, are largely empty of eggs; yet the different segments of one worm will differ widely in this particular. Eggs are often caught among the setæ and at any other points where they can be held.

"Specimens in confinement after copulation may be aroused into mild phosphorescence for at least an hour." Fig. 2 represents the appearance of a female and three male *Odontosyllis* at mating time.

Let us now examine the structure of the worm and try to determine the source of the luminous material. The writer scarcely can agree with Galloway's suggestion that this substance can come from the eggs or the body fluid that accompanies them. All our studies go to show that light comes only from a definite luciferine, and that this luciferine must be elaborated by specific cells organized for this purpose. Furthermore, such cells appear to have been in every case some form of epithelium or epithelial glands or derived from an epithelium. In this simply-organized worm we would expect to find such cells lying in the external epithelium and scattered pretty generally over the surfaces that have been observed to light when the animals are breeding, as has already been described.

Galloway describes two types of gland-cells in the epithelium of the worm, and makes the suggestion that the type designated by him as "regular" gland-cell is the origin of the creature's luminosity. This regular gland-cell is marked by its form, that of a

truncate cone with the larger end placed distally (Fig. 3, *A*) and with its smaller proximal end reaching only about two-thirds of the way down to the basement membrane. The inner end of the cell's cytoplasm has a reticulated or alveolar structure, while the outer part has a proximo-distal striation. The nucleus is large, of the glandular type, and is situated in the middle of the cell.

The other type is so evidently a mucous gland-cell that we will

FIG. 2.

The mating of *Odontosyllis* at Bermuda as seen from below the surface of the sea. Female worm describing rapid circles and twists on the surface and throwing off eggs and light material. Two males attracted by the light and approaching, themselves lighting, to fertilize the eggs. (Drawn by E. Grace White after the descriptions of Galloway and Welch, Cary, Linton, and others.)

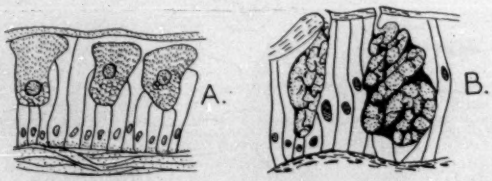
not describe it beyond saying that its content is a reticulated mass that answers all tests for mucin (Fig. 3, *B*).

The writer, after reading Galloway's beautiful description of the luminosity of this worm at breeding time, was not satisfied that the "regular" gland-cells, or even the twisted or mucous cells, were capable of producing so much light in so short a time, especially of throwing off a luciferine that glowed for an appreciable time in the water after having become separated from the body. We have seen many instances of organisms where the light

material was a fluid and where it was impossible to separate it from the body in a luminous state. The polynoid worms are examples of this, also the worm *Polycirrus*, as well as many other organisms. So it became necessary to look for a gland in which some considerable amount of luciferine, in the form of definite granules of a considerable size, could be formed and stored, to be thrown out to produce light much in the same manner as *Pholas* and *Chætopterus* do.

These glands, he believes, are to be found as modifications of the setegenous glands in the parapodia of this worm, both in the male and in the female (Fig. 4, *l. g.*). It still remains to actually see the light and to prove this working hypothesis true, but the structure and staining power accord so well with the many other

FIG. 3, A AND B.



Two bits of body epithelium from *Odontosyllis*, showing two kinds of gland-cells as described by Galloway and Welch. *A*, regular gland-cells (light-cells?); *B*, mucous cells. (After Galloway and Welch.)

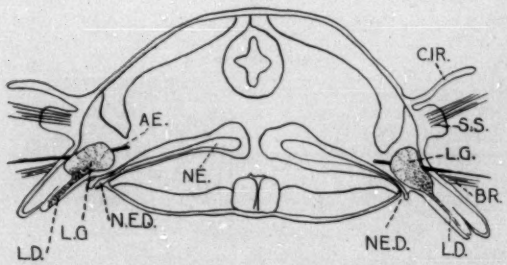
well-known light organs that it seems most probable that these are the real and main light organs, although it is possible and even probable that a few scattered epithelial cells—for instance, the "regular" gland-cells of the skin—may light also at breeding time or even at any time when they may be stimulated.

In Fig. 20 of Galloway's paper (see Fig. 4) it can be seen that the parapodium consists of an upper notapodium bearing a cirrus (*cir.*) on its upper lobe and with swimming bristles (*s. s.*) and a supporting aciculum (*ac.*) projecting from its lower lobe. The ventral portion of the parapodium or neuropodium consists of an upper lobe with a bunch of fine bristles and several acicula projecting from it, and a lower lobe through which the nephridial outlet passes. The basal portion of this neuropodium is occupied by a large gland which in other worms is used to produce the bristles or setæ. In this worm it appears to be devoted in part

to the secretion of the light substances. The real setegenous portions of the gland are closely applied to, and surrounded by, the light-producing portion. Still, such portions as belong to the bristles specifically are quite easy to differentiate from the large light-producing lobe, both by their staining reactions as well as by their structural relations. This gland empties by a duct (*l. d.*) through the tip of the neuropodium.

Fig. 5 shows a view of part of a parapodium, from about the middle portion of a female worm with this gland in place. So large is its mass that Galloway mistook a lobe of it for a glandular

FIG. 4.



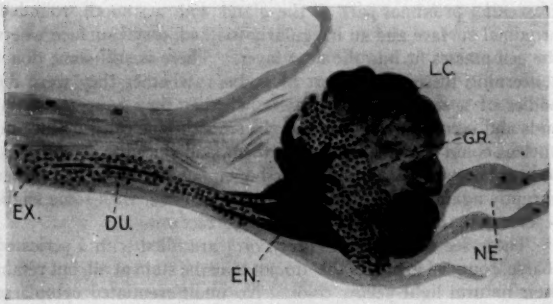
Line diagram of a segment from the middle part of the body of a female *Odontosyllis*. *cir.*, cirrus; *s.s.*, swimming setæ; *l.g.*, light-gland; *ac.*, aciculus; *ne.*, nephridium; *ne.d.*, nephridial duct; *br.*, bristles; *l-d.*, light duct. (Drawn by E. Grace White.)

portion of the nephridium. The nephridium, however, can be traced, as a single almost straight tube, past and through a portion of this gland, and can be seen to have no organic connection with it. The relation of the gland to the various bristles of the worm make it somewhat harder to differentiate as a luminous organ, rather than as a gland whose sole function is to produce luciferine.

The gland is formed by the recession of a number (possibly 35) of gland-cells from the epithelium of the dorsal lobe of the neuropodium. These cells retreat up into the base of the parapodium and form a single ovoid mass which varies in size in the different segments of the worm, and, according to its size, etc., is slightly modified in shape to permit of the passage through this base of the nephridial tube, three acicula and a bunch of bristles (not the swimming bristles).

All of the cells of this mass retain their glandular communication with the lower side of the dorsal lobe of the neuropodium through their ducts, which do not merge into one common duct, but, apparently, into several. The point of exit of the ducts is through a specially-arranged, muscle-free portion of the parapodial wall, and there is a surrounding ring of muscular tissue that can probably prevent the discharge of the light material from the ducts except during the breeding period. This gland should be studied at some period when the animal is not near the breeding time in order to see if this duct is entirely shut off by a growth of

FIG. 5.



View from in front of a section through part of a parapodium of *Odontosyllis* containing a light-gland. *lc.*, light-cells; *gr.*, granular masses connected with light-cells; *en.*, accessory cells of light-gland; *du.*, ducts of two kinds from light-gland cells; *ex.*, point of discharge of light-gland cells; *ne.*, nephridium. (Drawn by E. Grace White from a section.)

the epithelium that would have to be ruptured when the next discharge took place.

The cells that compose the gland are of two or three varieties that are well differentiated by a stain of Delafield's hæmatoxylin, and eosin or erythrosin (Fig. 5). They may be thus made to show three (or two) groups which lie approximately proximally or distally from one another and remind one much of the arrangement of the two kinds of light-cells in the mollusk *Pholas;* also, their secretions empty from the ducts in separated but contiguous streams, so that we probably have a compound gland secreting the catalytic enzyme as well as the luciferine.

The most proximal portion of the gland (Fig. 5, *l. c.*) consists of cells that are larger than the rest of the cells in the gland and have an elongate oval outline terminating at its distal end in a series of tube-like ducts (Fig. 5, *du.*) that run through the rest of the gland to empty at the end or near the end of the dorsal lobe of the neuropodium (*ex.*). The proximal cytoplasm of this cell is massive and shows a series of fine vacuolated spaces that seem to form a branching series of channels in which the secretion of luciferine probably takes place. With Delafield's hæmatoxylin or with hæmalum this cytoplasm stains a light transparent blue and shows a single nucleus of moderate size in some part of its mass. The bodies of these light-blue, homogeneous cells form a compact, crescentic, proximal part of the gland with a smooth, rounded, proximal surface and an irregularly-toothed, distal surface where the cell masses fit into the next layer. There is still some doubt concerning these second sort of bodies: whether they were the bodies of a second set of cells or whether they were the distal ends and secretion reservoirs of the smooth blue cells. Since no nucleus could be demonstrated in them, and since the smooth blue cells did not show a clearly-defined duct, but seemed to end rather abruptly against the second sort, it is concluded, with some slight reservation, that the latter idea is the correct one.

These second masses (Fig. 5, *gr.*) are filled with a series of coarse, rounded granules that do not take the stain at all, but retain their natural light-yellow color. No undifferentiated cytoplasm whatever appears in connection with them, and they are therefore to be looked upon as the secretion reservoirs of the light-blue cells, the whole structure, with its tube-like duct, forming the light-cells of the animal. The granules extend from the cell into the ducts and so out to the openings between the hypodermal cells on the end of the neuropodium, where they discharge. These granule-filled reservoirs form a narrow zone of one or two thicknesses between their light-cells and the distal cells which form the outer zone of the gland. The granule-filled ducts of the light-cells are collected and pass in a rather distinct bundle not through but on the outer side of the gland. This does not appear well in the figure.

The third set of masses (Fig. 5, *en.*), a distinct group of longer, narrower, and more elongate cells, are placed in the distal part of the gland and are also much smaller than the light-cells,

even without the mass of their reservoir added. These cells will be called the enzyme cells or luciferase cells. A slight doubt still remains as to whether they are for this purpose or are merely mucous glands, but they present some notable differences from the real mucous cells in the skin. The nucleus is not a flattened proximal structure, but is round and appears in the centre of the chief cell-mass. The content of the cell is granular, more finely granular than the light-cells, and with Delafield's hæmatoxylin it stains a dark blue, just as in the case of the distal layer of cells in the light organ of *Pholas*. The ducts from these cells also gather into a distinct bundle and accompany the bundle of light-cell ducts out to the point of opening on the neuropodium. Some few of the ducts sometimes get mixed with the duct-bundle of the light-cells, but this is only occasional.

It seems to the writer that here we have a very complete and efficient light-gland that accounts in every way for the bright external light shown by the worms when mating. No comparison was made between male and female, but it is thought that the glands must be very much the same in both. The large size of the light granules would readily account for the persistence of the light in the water, just as it does in *Chætopterus* and *Pholas*.

A more complete study should be made with an abundance of material and a careful physiological study of the animals in the field.

POLYNOID WORMS.

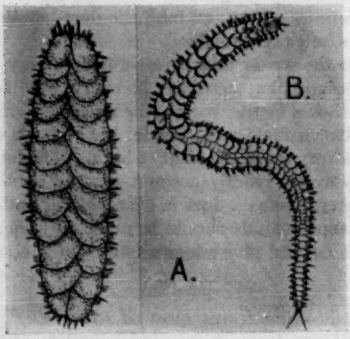
In these interesting forms most of the species are luminous. They vary in form from short, stout annelids like *Lepidonotis* (Fig. 6, *A*) to longer and more slender species like *Polynœ squamata* and *Acholœ astericola* (Fig. 6, *B*). These worms are poor swimmers, and their usual haunts are among stones and gravel and shells on the bottom of littoral regions, from low tide out to several fathoms, where they are most abundant, and to deeper waters, where some few of the species are found. A few forms are parasitic or commensal with other animals, as is well shown by the form *Acholœ astericola*, that lives only on the under surface of the arms of the brittle star *Astropecten aurantiacus*.

The most important structural feature of these creatures in connection with our light studies is a double row of so-called "scales" that run down the entire dorsal surface, one row on each side of the median line, with a more or less considerable

portion of the median surface of the back, between the rows, left bare. These " scales " are not such in the sense that we usually speak of such structures, as in fishes, etc., but are flattened portions of the animal's integument or body-wall, consisting of a mesodermal core covered with the reflected epithelium of the body. They are spoken of as Elytra.

Each elytrum is attached to the body by a stem of the same fleshly substance, through which a nerve and blood supply runs and is distributed mostly to the upper surface and edge of the

FIG. 6, A.



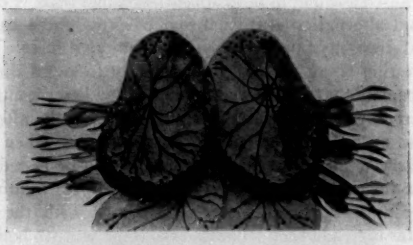
Sketch of *Lepidonotus squamata*. *B*, sketch of *Acholæ astericola* to show form. (Adapted from Kutschera.)

structure. Fig. 7 will give a good idea of this arrangement in *Acholæ astericola*, especially when one compares it with Fig. 6, in which the outer structural arrangement can be seen in a more general way.

The lighting of these worms is characteristic: like that of so many other light-producing creatures, it is a reaction to a chemical, mechanical, electrical, or thermic stimulus. But it follows certain rules that do not obtain in some of the others. Falger describes it from careful experiments in somewhat the following manner: When undisturbed the worm shows no light, but a weak mechanical stimulation, such as the slight shaking of the dish of sea-water in

which it is, results in a very weak shimmer on the edges of the scales. When the creature is gently touched with a needle or a glass rod the light becomes stronger and the luminous edge of the scale is widened. First the part touched or the nearest scales begin to shine, and the luminosity spreads rapidly, both backward and forward, from this point. Not all of the scales light evenly, but with considerable differences of intensity. Falger thought this might be due to different degrees of sensitivity or to different stages of secretion of the luciferine. The light lasted a few seconds, but a weak glimmer might follow, a second or two after

FIG. 7.



Two elytra in position on a segment of the body of the worm *Acholœ astericola*. The point of union of body and elytrum by a pedicel is indicated by the oval area. Nerve is seen rising out of body through pedicel and branching over elytrum. "Teeth" are indicated on anterior edge of elytrum and light organs on posterior half. (After Kutschera.)

the main display was over. The light was greenish-blue and so strong that it could be seen in a moderately-lighted room.

When a drop or two of hydrochloric acid was poured in the water a very intense light was produced. This appeared as a strong flash, followed by a weak but lasting display. Strong alkalies also stimulated to light production, but not so well as the acids.

A fresh worm in normal sea-water was subjected to a slow, constant rise in temperature of the water. A very weak light began with the first rise in temperature, and this light increased as the temperature rose. It was at its strongest when the water attained a temperature of 40° C. In this amount of heat the animal soon died. Another fresh worm was thrown into water

of 40° C., and after a short, strong flash of light it also died. Cold was not tried.

Electrical stimulation was the most successful means of experimenting with the light, as the animal was not permanently injured and the stimulation could be measured with great exactness. Both the direct and alternating currents were used. The wet animal was laid on a glass plate and non-polarizable electrodes were applied to its ends. When a direct current from the one-volt batteries was applied, the whole worm lighted equally, and when this current was shut off the light persisted in a weaker form until the current was once more applied, when it appeared in its strong intensity again. An instantaneous change in the direction of the current caused a bright light to appear for a moment. A current of very rapid alternation was then applied from three batteries, a combined strength of three volts of electromotive force. This gave the interesting result that the light actually followed the alternations so rapidly that it appeared to vibrate. When the current was lowered the light became less, but still followed the alternations. This went on for from twenty to thirty minutes, when the light became very weak. But the worm could then be rested in fresh sea-water for a few hours, when it was capable of lighting again.

Interesting experiments were performed with the separate elytra after they had been separated from the worm's body. Such "scales" lived and were capable of lighting for a long time. When first removed they lighted brightly and shone of their own accord for a number of minutes. They then rested dark until some stimulus caused them to illuminate again. Some lived so for sixteen hours.

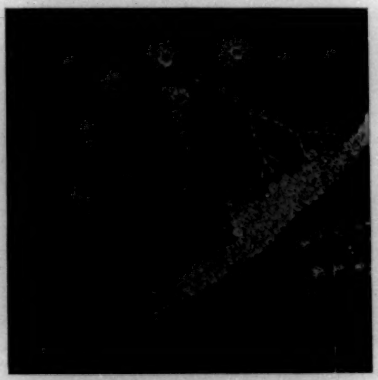
Dr. Fritz Kutschera followed up the work of Falger with more intensive studies of the conditions under which the worms in question will light, and, particularly, he tried to find out how the luciferine was secreted and whether it was consumed to produce the light in cells or in glands, or whether it was emitted from the glands and the illumination took place outside the body.

Kutschera found that the animal always lights progressively toward the tail when stimulated at any point of its body. When the stimulation is mechanical and the whole creature is shaken or moved the light may appear cephalad of the point of stimulation, but in this case the anterior light is caused by an anterior and accidental stimulation and not by a nerve impulse passing forward.

Even when cut suddenly in two parts it was only the posterior part that lighted.

It seemed impossible to demonstrate the emission of any luciferine from the surface of the lighted "scale" borders. No light could be rubbed off on the fingers or on paper or in any other way be made to show independently of the tissues. One very interesting way of treating the creature was to place it upon dry filter-paper, so that practically all water was removed from the outside of its cuticle. Under these circumstances it becomes rigid or still and stops the almost continuous movements that go on when it is

FIG. 8.



Enlarged surface view of portion of posterior half of one of above elytra. The branching nerve is shown with several light organs situated on its twigs. (After Kutschera.)

immersed or very wet. When this dry rigidity was at its height the electric current was applied and light appeared as usual. Under the magnifying glass or low power of the microscope the light was seen to come from particular points, which were most numerous on the edge of the "scale."

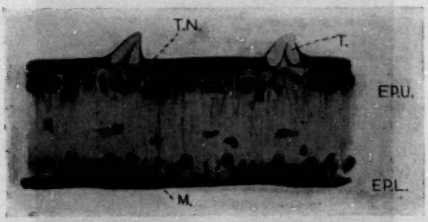
Kutschera very correctly decided that the question would best have further light thrown on it by a careful histological study of the tissues, and he made careful sections with appropriate fixation and stains for this purpose. His results may be summarized as

follows: When examined from above *in toto* the "scale" is seen to be a cellular structure whose whole upper surface is covered with a layer of large cubical epithelial cells, the outlines of which appear rounded rather than flat-sided. This indicates that some small space separates them and is filled with an extra cellular substance (Fig. 8).

It can then be seen by a little deeper focussing that a nerve rises out from the pedicel that holds the "scale" to the body, and that this nerve, after swelling into a ganglion, branches into successively finer branches that radiate in all directions through the flat scale and end in abundant points that are most abundant in the peripheral outer zone of the structure (see Figs. 7 and 8).

Where each nerve twig ends is a raised papilla, under which a

FIG. 9.



Vertical section through an anterior region of above elytrum. *t.*, "tooth" on dorsal surface; *t.n.*, nuclei of "tooth" region; *ep.u.*, upper hypodermis of elytrum; *ep.l.*, lower hypodermis. (Modified from Kutschera.)

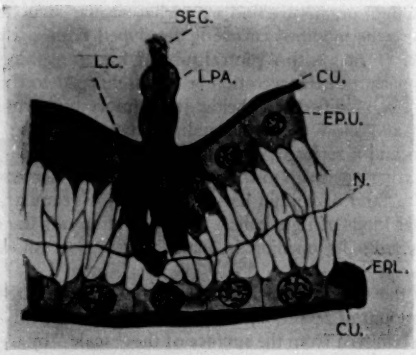
number of smaller darker nuclei are collected, indicating the presence of a number of smaller cells that lie deeper in the substance of the elytrum than the epithelial cells. Two sorts of such papilla are found. On the anterior edge of the "scale" are tooth-like projections with but few nuclei beneath them. These are mere mechanical organs of some unknown function, or, possibly, sensory organs of touch, and are not the light organs. They are comparatively fewer in number than the second form of papilla, and are shown in Fig. 9, which is a section of an anterior portion of the elytrum.

The second kind of papillæ is found mostly near the posterior edge of the scale, and have the largest number of the dark nuclei and their cells around and below them, and have proved

to be the real light organs. With the low power of the microscope they can be seen to be points of light production when the living animal is illuminating.

In the posterior edge of a vertical section of the scale taken on its antero-posterior line we can now see the structures of these light organs more plainly (Fig. 10). This section shows the scale to have an upper and a lower epithelial surface, with a loose connective-tissue mass between them (Figs. 9 and 10). As in all worms, this epithelial layer is a hypodermis and is covered with a cuticle of considerable thickness. The lower hypodermis

FIG. 10.



Vertical section through a posterior part of the same "scale" or elytrum, to show a single typical light organ. *l.c.*, light-cells; *l.pa.*, light papilla; *sec.*, secretion; *cu.*, cuticle; *ep.u.*, upper hypodermis; *ep.l.*, lower hypodermis; *n.*, region of nerve distribution. (After Kutschera.)

has evenly-developed muscle-bundles in its cytoplasm (Fig. 9, *m.*), very much as the epidermis of certain cœlenterates has. No basement membrane is present, but the cells are connected with the underlying connective tissues by several branching strands of their proximal cytoplasm, as is often seen in the worms and arthropoda and but seldom in the mollusca and vertebrata (Figs. 9 and 10).

The upper epithelial cells are larger and possess larger nuclei than the lower cells just described. The cytoplasm is denser and contains a closely-packed mass of small round granules, usually

colorless, but altered to pigment granules in certain regions where the elytrum appears colored, usually black or dark brown. We can now describe the structure of two kinds of projections on the upper surface, the " teeth " and light organs in terms of these cells.

Each tooth consists (Fig. 9) of a short, modified, cone-shaped area of the cuticle, with its lumen almost opening to the outside. This cuticle of the tooth is thicker than the general cuticle and stains lighter. Immediately below it are a few modified epithelial cells that have smaller, irregular nuclei placed below the level of the hypodermis and belonging to the modified cells that form and support the structure.

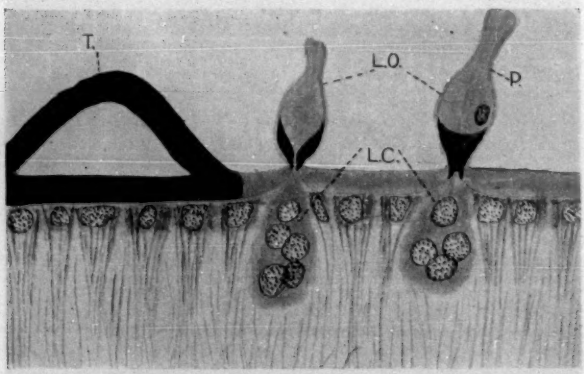
In the light organs we find somewhat similar structures (Fig. 10). Here the modified cuticle is developed from a cone into a tall papilla (*l. pa.*) with a central tubular lumen opening through its top to permit of the secretion being discharged to the exterior (*sec.*). The modified cells below it are more numerous than in the tooth and show a more glandular nature, having a darker cytoplasm and a series of lines of secretion that reach from the smaller darker nuclei up toward the tube. Their secretion is evidently of a fluid of colloid nature, and is not granular, as in so many other kinds of light-cells. This secretion fills the tube, and protrudes from its opening in many cases, as is shown in the figure (*sec.*).

From the structure of this organ we can see that there is but a small amount of secretion, and from the fact that this secretion cannot be removed from the surface of the " scale " by objects that touch it we can infer that it is burned and the light produced either in the cells, the tube, or almost instantly upon being discharged from its outer end. The tube may be used only to discharge the products of this combustion, and the enzyme or catalytic agent must be made by the same cells that make and send out the luciferine.

The writer has examined the " teeth " and light organs in the form *Lepidonotus squamata* and finds some interesting differences. The " teeth " are much larger and more highly specialized organs than in *Acholœ*, with a base and a closed top, which thus encloses a central space in the " tooth " that is hollow. Fig. 11 shows this in section. The modified epithelial cells that support the " tooth " are not prominent features, being smaller and fewer than in the unmodified hypodermis.

The light organs, while essentially the same as in *Acholœ*, are fewer but larger than in that form and, so far as the glandular portion is concerned, are more definitely organized (Fig. 11, light organ). The modified hypodermal cells that compose it have larger, heavier bodies and their cytoplasm is darker staining, owing to some granular content that is evidently luciferine and its allied products. These cells, too, are not spread about, but are gathered into a very definite mass that shows a definite oval outline (Fig.

FIG. 11.



Vertical section through a posterior portion of the elytrum of *Lepidonotus squamata*, to show one light organ (*l.o.*) and one "tooth." *l.c.*, light-cells; *l.p.*, light papilla with tube and secretion; *t.*, tooth. (Original drawing.)

11, *l. c.*). The nuclei of these light-cells also differ from the corresponding nuclei in *Acholœ* in being larger than the hypodermal nuclei. Their character shows all the indications of secretory activity, which suggests the possibility that *Lepidonotus* can shine more brightly or longer than can some of the forms already worked upon.

The connective tissue lying between the two layers of hypodermis forms a loose mesh-work with but few nuclei and with large spaces that probably contain blood, although blood-cells are hard to find in it. The nerves branch and ramify through the

middle level of this connective tissue, and careful preparations and study would undoubtedly show some definite method of blood circulation through capillaries and sinuses.

The use of this light to the animal seems quite apparent. It is used to protect the animal in the form of what may be termed a "sacrifice lure." It has already been explained how, if the worm is cut in two parts, the posterior part will light and wriggle, while the anterior part will remain dark and seek concealment. So, too,

FIG. 12.

Picture to show the method and use of lighting by a polynoid worm on Maine coast. A crab, *Cancer irroratus*, has just cut one of the worms in two with his claw. The anterior portion seeks the shelter of a stone. The posterior portion, together with detached scales, lights up and moves with wriggling movements. (Drawing by J. Bruce Horsfall from descriptions by the writer.)

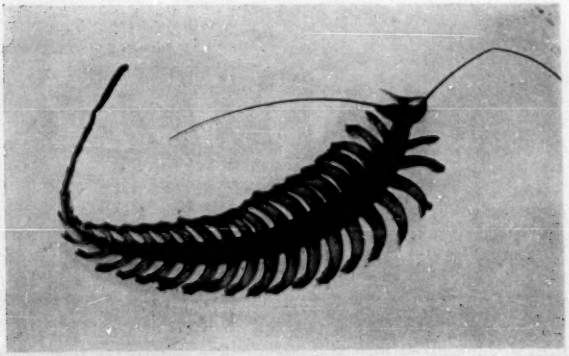
will a single "scale," if detached from the body, start to shining at once. The nervous mechanism appears to act in an inhibitory manner, and, in consequence, any injury to the nerve control from the brain, by cutting or otherwise, seems to initiate the lighting process through the ganglia in the scale peduncles. Fig. 12 shows a view of this worm as it appears when lighted in the sea; also when it has been attacked by a crab that has cut it in two parts and torn off some of its "scales." The writer finds that in the waters

of Florida (Dry Tortugas), as well as in New England waters (South Harpswell, Maine, and Wood's Hole, Mass.), this worm is eagerly sought and devoured by several fishes and crustaceans. It, together with its neighbors on gravelly bottom, the luminous brittle stars, forms the chief food of the haddock on the Maine coast and its fishing banks.

THE TOMOPTERIDÆ.

This group of annelid worms are highly specialized for a pelagic life and are found, usually on the surface, in all seas. Some of the largest kinds are found in the cold waters of the boreal

FIG. 13.



Photograph of a specimen of *Tomopterus helgolandica* from the coast of Maine. (Photo by Dr. Henry B. Bigelow.)

region, while the largest number of species occur in the tropical waters of all oceans. Nearly all are exceedingly transparent in texture, like so many pelagic animals, but a few, especially some tropical forms, are decorated with a few highly-colored chromatophores which give them a brilliant but limited color pattern.

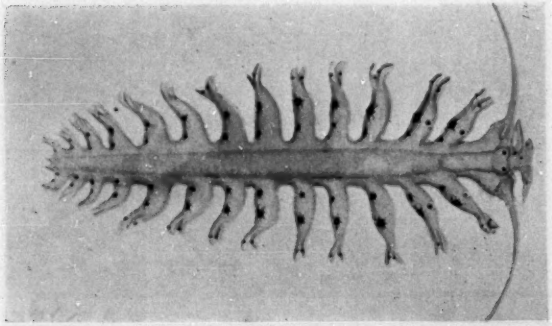
Fig. 13 shows a photograph of a large, transparent species from the waters of the gulf of Maine, and Fig. 14 represents *Tomopterus rolasi*, a colored form (color represented by black areas) from the British West Indies. Both figures show the characteristic shape of the various kinds of these worms, which is

remarkably uniform among the different species. It will be noted at once that the parapodia are highly developed as swimming organs, that are used by the animals to propel themselves rapidly on the surface of the water.

Vejdovsky was one of the first (in 1878) to note that a few symmetrically-placed, highly-pigmented, rosette-shaped organs were to be seen on some of the anterior limbs. Not all of the species possess these organs, but the majority of them do.

Von Greef, while studying the many pelagic invertebrates in the neighborhood of the island of St. Thomas, found two species,

FIG. 14.



Drawing of a specimen of *Tomopterus rolasi*. The eye-like luminous organs can be seen on the first pair of parapodia or "oars." (After von Greef.)

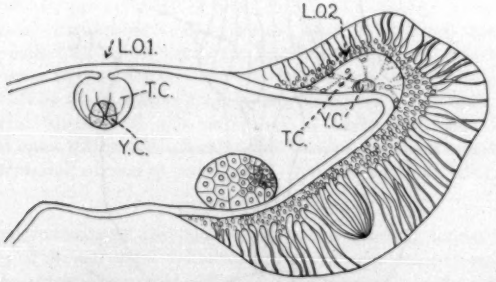
Tomopterus rolasi and *Tomopterus mariana*, in which he describes these organs more carefully and finally came to the conclusion that they were light organs. He does not state clearly just how he decided this important question: whether he actually saw the light, or whether he made the decision on account of their structure.

In the fall of 1908 Kiernik captured a species of *Tomopterus* off the coast of Norway and confirmed the conclusions of von Greef by putting them in a dark room and actually seeing the light that they gave when stimulated. He did not make a careful study, either physiological or histological, of the power, and this

worm, therefore, presents the need of, and the opportunity for, such work still to be done.

We will further examine the question by showing the partial structural work of von Greef on these organs as shown by *Tomopterus rolasi* and *Tomopterus mariana*. In both species he shows two forms of the light organ. The larger form, as shown in *Tomopterus rolasi*, consists of four large structures placed, one each, in the middle of the length of the first two pairs of oar-like appendages. In optical section (Fig. 15, *l. o.* 1) these show a central, melon-shaped mass of yellow cells (*y. c.*) placed in the proximal part of a much larger melon-shaped body of large

FIG. 15.



Drawing of an optical section of one of the first two parapodia on the body of *Tomopterus rolasi*. Partly diagrammatic. *l.o.*1, light organ on the "oar"; *l.o.*2, light organ on the "fin"; *t.c.*, transparent cells; *y.c.*, yellow cells. (After von Greef.)

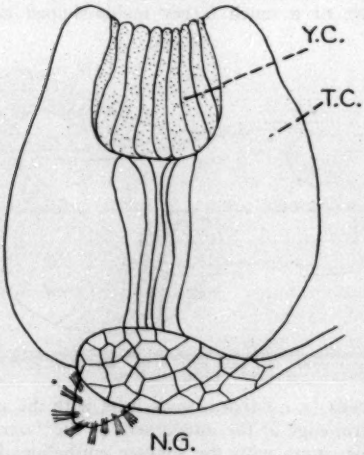
transparent cells (*t. c.*) that is sunk level with the surface of the anterior ventral edge of the integument of the "oar." The continuity of this organ with the surface epithelium is fairly well indicated in the figure, although von Greef did not have preparations that definitely showed the histological structure of the organ.

The second form of light organ is shown in the same figure (Fig. 15, *l. o.* 2), and is placed in the tissue of the "fin" that is found on the end of each "oar." Two of these fins occur on the bifurcated ends of each oar, and one of the light organs in each fin on most of the oars brings the total number of this second kind of organ up to something like twenty in all.

The same melon-shaped mass of yellow cells appears to form the principal structure in this organ as in the last (Fig. 15, *y. c.*);

and this yellow rosette is placed in a proximal position in a much larger mass of large, transparent cells, as in the last case. But the larger cells do not form as definite a melon form as in the oar organ; and a still wider modification is the way in which the whole mass of the organ is below, and covered by, the thick body epithelium and its basement membrane. No trace appears of any previous invagination, yet the writer feels certain that this entire organ is formed by an epithelial invagination in the development of the worm.

FIG. 16.



Drawing of one of the large light organs of *Tomopterus mariana*. *y.c.*, yellow cells; *t.c.*, transparent cells; *n.g.*, nerve ganglia. (After von Greef.)

An examination of one of the "oar" organs of *Tomopterus mariana* will show more concerning the origin and meaning of these organs, perhaps, than in *Tomopterus rolasi*. Here we find the same sort of elements as seen in *Tomopterus rolasi*, but the arrangement is different, more primitive (see Fig. 16). The large melon-shaped rosette of larger, transparent cells (*t. c.*) is present and is imbedded in the integument in a position that brings its distal end flush with the outer epithelium of the appendage and

shows its origin from the hypodermis. The yellow body is also present (*y. c.*) and placed in the central axis of the transparent cells, but, instead of being in a proximal position, it lies in the distal end, with the tops of the yellow cells (here stippled) level with the tops of the transparent cells and also forming, morphologically, a part of the hypodermis. This organ has also been further described by von Greef in that he has shown the presence of a ganglion (*n g.*) at its base, with a nerve coming to it and with fibres passing out of it, up between the transparent cell, to attach themselves to the bases of the yellow cells (Fig. 16, *y. c.*).

Unfortunately all of these figures and descriptions by von Greef have been made from living worms, or from very poor preparations, and no nuclei or other details of a cytological nature are given. From what we can surmise, however, it seems that the yellow cells must be the light-cells, and the transparent cells must be either a lens structure or nutrition cells connected with the organ. The whole matter presents an interesting opportunity for a careful histological and physiological study and should be worked upon with modern methods and with a sufficient supply of fresh material. It seems certain, still, that it is a true light organ.

CHÆTOPTERUS.

This remarkable and highly-specialized annelid worm is a member of the sub-order *Spioniformia*, and its species are found all over the world in tropical and temperate regions. It lives from low-water mark down to about fifteen fathoms in depth, near the shores of quiet branches of the ocean, buried in mud and sand and housed in a tough, parchment-like tube made from the secretions of its own integument. This tube is U-shaped, with the two exits projecting slightly from the ground, and the middle is considerably larger in diameter than the ends. Fig. 18 shows the shape and position of the tube.

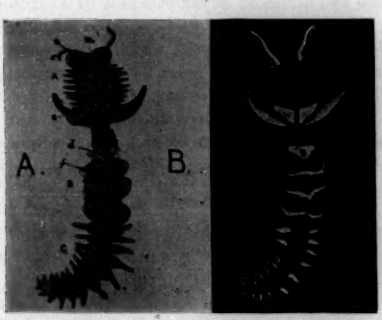
The tube is much longer and wider than the body of the worm, which can move about quite freely inside of it. The animal never leaves the tube, although at times it may reach out of it and even lie with a larger part of its body outside to get cooler and more agreeable water. Several crustaceans and worms live in the tube with it as commensals.

The worm is very soft-bodied and delicate, and in color a light yellow or flesh tint, often about the color of a tapeworm, thus

showing that it was intended for an indoor or cave life. Its eyes are small and almost useless, and it feeds on microscopic plant and animal life, which is caught by a current of water, the respiratory stream, driven by the three flat paddles in the creature's middle, and, becoming entangled in the slime on the surface of the skin, is drawn by the cilia in currents of slime to the mouth, where it is ingested.

This worm is one of the most brilliant of known luminous organisms. Fig. 17, *A*, shows it as it appears in daylight and *B* as it appears in a dark room under a moderate amount of stimulation. Here we can see that not all parts of the body light with an

FIG. 17.



Two figures of *Chaetopterus variopedatus*, one in daylight to show the regions of the body; another in the dark to indicate which of these regions are light-bearing. (After Panceri.)

equal intensity, but that certain parts are more capable of luminosity than others. When a greater stimulus is applied the light becomes more widely distributed, but certain parts retain the lead in brightness. The stimulus may be chemical, electrical, or mechanical, it does not seem to matter which.

Upon studying the living, shining animal more closely and with a hand lens one notices that the light is actually given off from the body as fine clouds of luminous material that rise in the water; also, that the apparent spread of the luminous localities is not due to the operation of other glands before unlighted, but to the spread of this secretion through the water to the unlighted

parts which it masks with light. Fig. 18 shows the appearance of the worm if the observer could look at the interior of its tube from the side. The writer wishes to say that he has seen eels pull *Chætopterus* out of its tube and has often found the anterior region of their body as well as occasional whole worms in the stomach when the eel was captured and opened early in the morning, after feeding on the sand and mud flats.

The light is of the usual greenish-blue, except that, when the worm is almost exhausted or is very weakly stimulated, pale-lilac or violet flashes pass over parts of its body just before the stronger blue-green glow appears. When a lighted candle is in the dark room at the same time the light appears green.

The light comes from the skin and is evidently an external secretion of luciferine, because it comes off on the fingers if the animal is handled while lighting; also, several strong, fresh specimens glowing in a bucket of sea-water will throw out enough of the material, and it will glow long enough, to make all of the water in the vessel of a milky luminous color.

A number of workers have studied this interesting worm. Panceri wrote about it, and Dubois used it in some of his studies on animal light. Panceri described the habits of lighting and showed the regions of the integument that possessed this power to the greatest degree. In recent times Enders has studied the growth and habits of the worm and showed that the young, free swimming larva was capable of lighting, especially in the skin of the ciliated rings with which it is provided.

The most serious work on this power of light production has recently been done by Trojan, who did careful histologic and experimental work on the subject in a paper devoted exclusively to this phase of the organism's activities and to its tube building. The outer form of the worm is important in studying its lighting powers, and Fig. 19 shows the dorsal surface of a well-fixed and preserved specimen. The body is divided, for convenience of description, into three regions: an anterior region, a middle region, and a posterior region. We will note the locations of the lighted areas, as these are briefly described, and refer the reader also to Panceri's figure (Fig. 17) for further exposition of this point.

The anterior region is composed of some ten segments, all massed together into a body, sometimes called the "head" by the

uninitiated. The real head is small and is fused into the anterior part of this mass, its two small tentacles projecting from the mass. These tentacles are at times partly hidden by the curled edges of the large " under lip " which ends dorsally in their neighborhood. These tentacles are the seat of brilliant light when the animal is aroused, while practically none is shown on the rest of the anterior region.

The middle region is very highly specialized in form and

FIG. 18.

Drawing to show the habitat and appearance when lighting of *Chætopterus*. Eels ordinarily capture and eat a considerable number of these large worms. They usually break off and devour the anterior region, leaving the rest of the body in the tube to regenerate a new part. The tubes and ground have here been shown in imaginary section. (Drawn by J. Bruce Horsfall.)

structure. One of its first segments shows two long, wide, wing-like processes, the notopodia of the twelfth segment, which are developed from lobes of the parapodia belonging to this segment. This wing shows a triangular spot of very brilliant light on the anterior side of its base; also, its upper edge shows scattered spots of light, thick set on the extreme edge and more scattered toward the middle. The " wing " is used in " plastering " and smoothing the inside of the tube with the filament-containing secretion of certain epithelial cells.

The next portion of the middle region is almost bare of appendages, and the dorsal body wall is so thin and fits the digestive tube so closely that it appears to be absent and the dark-green gut seems to lie exposed in several bends and coils on the ventral body wall. In its midst appears one apparent remnant of the dorsal wall of the thirteenth segment, which is a knot of tissue of the same color as the usual surface of the rest of the animal. This structure is known as the accessory feeding organ (Figs. 17 and 19). It is one of the brightest spots on the worm when it is illuminated, and it is here that we must look for a good number of light-cells.

The latter part of the middle region is occupied by three large, rounded, fan-shaped paddles that represent the notopodial parts of the parapodia on the fourteenth, fifteenth, and sixteenth segments. These " fans " are breathing fans and are used to propel the respiratory and nutritive stream of sea-water that runs through the tube. Their posterior surface is illuminated when the worm is aglow. The light appears in spots, and so we will expect to find the light-cells scattered, either singly or, more probably, in groups in this region.

The rest of the worm's body, the posterior or third region, is least specialized of all and consists of a large number (from fifteen to fifty) of segments, all much alike. This is the sexual region of the animal, in whose body cavity the sperm and eggs are developed in the male and female individuals. Each segment has a well-developed lateral notopodium of large size, with a truncate base and a longer distal lobe. Each base shows, on its posterior edge, a thickened mass of epithelium which, in the dark and when the worm is stimulated, gives rise to an abundance of light. So we must also examine these regions in our search for light-cells and their accessory tissues.

As to the creature's epithelium, it is of extraordinary development and differentiation. One of the most prominent sorts of cells is found in some thickened portion in several regions, and consists of long gland-cells filled with granules and also with fine coiled threads. These cells are secreting the material out of which the tube is built. As Trojan has shown, the threads are discharged and plastered against the inner wall of the tube with some cement substance probably derived from the granules in the same cells.

The next sort of cell is even more common, and its members are scattered very widely over the body, sometimes alone and at other

times in masses. They are very large mucous cells whose contents are not granules of mucin but large, reticulated masses of completed and dissolved mucus. Their need can be gauged by the enormous amounts of mucus that are always found on and about the worm when the tube is opened and the worm is handled. These mucous cells (Figs. 20 and 21, *m.c.*) are often mixed with the various other cells found on the body, and their function is very plainly indicated by their staining reaction as well as by the flattened and proximal position of the nucleus. In many cases they are lobed and compound cells. Their content is very soft and dilute, and in fixation they are apt to have the mucus shrunk somewhat. They also become quite hard and brittle if treated too long with the stronger alcohols.

There are now left to examine and study two other more or less common kinds of cells found in the integument of the worm

FIG. 19.

Drawing of an adult specimen of *Chaetopterus*, to show its appendages and the different regions of the body. (After Enders.)

and also to decide which of these are the light-cells, or if both are.

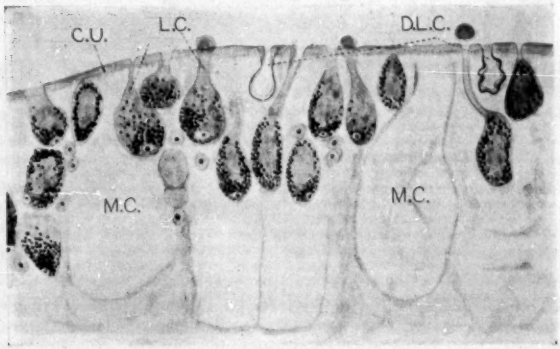
The first is a very simple cell found in large numbers on the deeper surfaces of the accessory food organ (this organ is a sucking disk and aids in no way to ingest any food), which is, we know, probably the brightest surface on the worm when lighting. These cells (Fig. 20, *l. c.*) are found imbedded in the epithelium, which is thick here and composed of mucous cells and undifferentiated hypodermal cells in about equal numbers. They are oval cells showing a dense granular cytoplasm, a distinct cell membrane, and an oval or triangular nucleus with a very heavy nuclear membrane, almost no chromatin granules, and a single large, spherical plasmosome, in which most of the chromatin seems to be situated. This nucleus lies directly against the proximal wall of the cell, usually in the middle, sometimes to one side, but always against the cell membrane.

The distal end of the cell is a duct of varying length, in any

group of cells, according to whether the cell to which it belongs is nearer or farther from the cuticle of the epithelium. If the cells are very numerous they may lie in two or more layers, and in that case those in the inner layers must have a duct that will reach between the cells of the outer layer and open through the cuticle. If, on the other hand, they are scattered and few in number, they usually all lie touching the surface with ducts of but the shortest length.

Some of the cells are emptying, and they appear to be of a

FIG. 20.



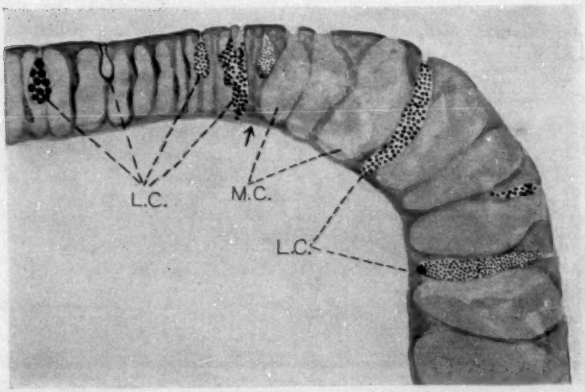
Drawing of a small portion of the epithelium from a fold of the accessory food organ on the fourteenth segment of *Chætopterus*. *cu.*, cuticle; *l.c.*, light-cells, some showing discharge of secretion; *d.l.c.*, discharged and emptied light-cells; *m.c.*, mucous cells. (Drawn from section by E. Grace White.)

secretory type that are destroyed by one cycle of secretory activity. Thus we find exhausted and empty cells near the surface in several cases (Fig. 20, *d. l. c.*). On the other hand, some of them seem to be younger and to stain darker, although it may be a renewal stage of another secretory cycle instead of the development of a new light-cell.

It seems fair to assume that these are light-cells on account of their position in this light-powerful region and also because of the absence of any other cell that appears able to perform the same function.

The second kind of cell that appears to be a light-cell is a distinctly granular one (Fig. 21, *l. c.*). It is elongate, reaching from the surface to the basement membrane of the epithelium, and is very narrow. It is most often found among the large mucous cells, and is particularly abundant on the edge of the large, fan-shaped notopodia, where we find a very bright light region when the creature is stimulated. These cells become less frequent as

FIG. 21.



Bit of epithelium from edge of one of the "fans" on the body of *Chaetopterus*. Arrow marks transition from posterior edge of the narrow band to the thicker epithelium-bearing mucous cells on the posterior surface of the "fan." *l.c.*, light-cells, one of them empty; *m.c.*, mucous cells. (Drawn from section by E. Grace White.)

we pass away from this edge, which also accords with the distribution of the light.

Fig. 21 shows a drawing of a vertical section of the edge of the fan, and it can be noticed that the extreme edge is marked by a band (here seen in cross-section) of undifferentiated hypodermal cells, very long and narrow and closely packed together. On both anterior and posterior surfaces of the fan these hypodermal cells assume a glandular condition and become the large mucous cells mentioned previously. This transition is very clearly seen in Fig. 21.

Scattered among the hypodermal cells of the undifferentiated band we find a few (five to ten in each section) large, granule-secreting cells of the kind mentioned above which are undoubtedly light-cells (*l. c.*). Most of them are found on the posterior edge of the epithelial band, although some may appear near the other boundary. Further, they are also found, more sparingly distributed, among the large mucous cells on the posterior surface of the fan. Some such may be seen in the figure.

These cells all have the same kind of nucleus that the light-cells on the accessory feeding organ had, of good size, proximal, and next to the cell wall but not flattened hard against it, and with one large plasmosome, in which all of the chromatic material of the nucleus seems to be stored.

The content of such cells is a mass of granules which differ in size in the individual cells but are all of one size in each cell. This variation is quite extreme, running from very small, fine granules up to extremely large ones. In the largest-sized granules a tendency is shown toward a softening of the individual grains, and it was not long before the writer was able to see a series embracing not only all these granular cells but having as its end in one direction the first type of light-cells as described above in the accessory feeding organs; so we are dealing with only one kind of cell, after all. Whether this series means a set of stages in the ripening of the cells or not could not be decided. The writer is inclined to disbelieve this, although he is open to conviction. It seems entirely possible that light may be produced from several-sized granules of the luciferine. We know that in *Pholas* the granules are all formed at once, of the same size in the real light-cells as described by Förster. The writer has seen, however, some fine-granuled cells even in *Pholas*.

The question as to the source of the enzyme, necessary as a catalyzer in all light production through luciferine, is still to be taken up in *Chætopterus*. To be sure, we have found several other organisms in our studies so far in which this point could not be adequately solved.

One suggestion is that the mucous cells may act in this capacity. So far as we have gone it has been noticed that both structurally and in their staining capacities the cells diagnosed as luciferase units have resembled mucous cells. So it may serve as a rather weak working hypothesis that the mucous cells of this worm act

both as a mechanical mucous supply and as producers of luciferase as well.

Again, there are long, narrow gland-cells in the hypodermis that stain blue with Delafield's hæmatoxylin and that always are found in the neighborhood of the light-cells. There is a possibility that they are collapsed mucous cells which have discharged. This idea is favored by their length and thinness. But they may also be the missing element that we are in search of.

The use of the light by *Chætopterus* is a puzzle. Living as they do in a tube underground, one cannot imagine any possible use for the light. On account of the duration of the light, which it owes to the large granules that the luciferine is formed into, the luminous cloud could be given off and caused to emerge from one of the entrances of the tube. The best we can do is to surmise that it has the same use as in the case of *Pholas*, which also lives in the ground and has an enduring light also.

EARTHWORMS.

We find in biological literature so many positive statements that earthworms sometimes illuminate that the subject cannot be ignored. The scientific standing of the observers demands a careful consideration of the matter. In 1670 Grimm and in 1771 Flanguergues describe it, and in later times Moquin-Tandon, Vejdovsky, Owsiannikow, Eversmann, Duges, Giard, Moniez, Stein, Matzdorff, Molisch, and Haupt have made mention of the fact. Many of these cases are concerning common species of earthworms that we know do not ordinarily light. Since the earthworms eat vegetable matter, the most probable explanation is that the illuminating worms have been eating some luminous fungus and that the light is derived from this fungus.

(*To be continued.*)

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

REPORT OF THE TENTH ANNUAL CONFERENCE ON WEIGHTS AND MEASURES, MAY 25–28, 1915.

THE report is a record of the proceedings of the Conference, which is composed of state and local weights and measures officials from various parts of the United States. It contains, among other matters, short reports of the condition of weights and measures work in about twenty-five states; and technical papers dealing with the testing of electric meters, railroad track scale tests made by the Bureau of Standards, a method of adjusting railroad track scales, a discussion of automatic scales, system of keeping records, and weights and measures work from the standpoint of an efficiency engineer. The Conference adopted at this meeting extensive and comprehensive tolerances and specifications for weights and measures and weighing and measuring devices, which are given in the appendix of the report, together with a model state law on weights and measures, previously adopted.

LIFE TESTING OF INCANDESCENT LAMPS AT THE BUREAU OF STANDARDS.†

By G. W. Middlekauff, B. Mulligan, and J. F. Skogland.

[ABSTRACT.]

SINCE the year 1908 the Bureau of Standards has inspected and tested the incandescent electric lamps which have been used in all departments of the government, amounting at present to about 1,250,000 lamps annually. The specifications under which these lamps are purchased are published by the Bureau as Circular 13 and are recognized as standard by the manufacturers as well as by the government. They are used also by many other purchasers of lamps.

Application of these specifications necessitates careful inspection and reliable life tests. The lamps are first inspected at the factory by Bureau inspectors, five per cent. taken at random from

* Communicated by the Director.

† Scientific Paper No. 265.

each package being examined. These must conform to certain specified requirements as regards bulbs, bases, filaments, vacuum, etc. Lamps which pass these requirements are then run on the photometer to determine their candle-power and the watts consumed, and if the required percentage of the lamps falls within the specified limits the lamp nearest the mean value of each group of not more than 250 lamps is selected, labelled, and sent to the Bureau to represent the group on life test.

Upon their receipt at the Bureau these samples, which at present amount to about 5000 annually, are measured for voltage corresponding to the efficiency at which it is desired to run them on life test. A life test is said to be *normal* when it is run at the efficiency required by the specifications, and *forced* when it is run at a higher efficiency. Carbon lamps are usually tested at normal, while tungsten lamps, on account of their long life at normal, are forced in order to complete the test without unreasonably delaying the delivery of the lamps they represent, which must be held by the manufacturers pending the results of the test. The life is specified as the number of hours a lamp at rated efficiency will burn until its candle-power has become reduced to 80 per cent. of its original value. In the case of forced tests the actual life must be corrected by the proper factors to correspond to normal (rated) efficiency.

In order to facilitate the photometric measurements of the life-test lamps and still secure a permanent, accurate, and, as nearly as possible, automatic card record of each lamp tested, certain modifications and additions have been made to the photometer used in this work. These include a watts-per-candle computer and a recording device by which observed values of candle-power, watts, watts per candle, and actual life are recorded on a separate card for each lamp. These records are made in such a way that life at forced efficiency may be corrected to life at normal without computation or reference to tables of factors.

The test lamps, having been rated as described above, are then ready for the life racks, where they are burned at the respective voltages found until their candle-power has dropped 20 per cent. In order to obtain reliable results the voltage must be accurately adjusted and carefully regulated during the test. The Bureau's life-test electrical equipment is so designed that by a system of auto-transformation any voltage from 78 to 260 may be obtained

and the exact value approximated to within one-tenth of one per cent. By a Tirrill regulator this voltage is kept within the specified limits of plus or minus a quarter of one per cent.

Another important element in a life test is the elapsed time of burning. This is accurately determined by means of an electric clock placed in the master-clock circuit of the Bureau. It is so arranged that the clock is short-circuited when current is not being supplied to the racks.

REGULATION OF ELECTROTYPING SOLUTIONS.*

[ABSTRACT.]

THE second edition of this circular, which has been entirely rewritten, is devoted principally to a discussion of the effect of various factors upon the deposition of copper in electrotyping baths, based upon the literature on this subject, and upon recent investigations by the Bureau of Standards. The limits of composition of solutions, temperature, and current density are defined, within which copper having the required tensile strength and ductility may be obtained. The circular also includes conversion tables for Fahrenheit and Centigrade temperatures, metric and customary units, and specific gravity and degrees Baumé. Definitions of important electrical terms are given, and also tables showing the weight and thickness of copper deposited by a given current in a specified time.

PROTECTED THERMO-ELEMENTS.†

By Arthur W. Gray.

THE paper describes a convenient mounting for protecting laboratory thermo-elements from damage by contamination or by mechanical strains.

The closed tube which covers the temperature determining end of the thermo-element has its open end cemented into one end of a flexible copper tube, through which the wires, properly insulated, pass to a head at the other end. Projecting downwards from this head is a glass tube which contains the ice junction. The head is provided with neutral binding posts for receiving the leads to the apparatus employed for measuring the electromo-

* Circular 52. Second edition.

† Scientific Paper No. 276.

tive force by which the temperature is determined, and contains phosphorus pentoxide to prevent moisture films from being deposited within the protective covering.

The ice-bath is contained in a vacuum jar which is protected by a metal case. By means of a bayonet joint this is suspended from the cover, which is fastened to a rod fitting the standard laboratory clamps. The head of the thermo-element telescopes with moderate friction into a split tube which projects upward from the top of the ice-bottle cover. When it becomes necessary to renew the ice, a slight turn of the case containing the vacuum jar frees the bayonet joint and permits lowering of the ice-bath without disturbing anything else.

Application of X-rays to Metallurgy. ANON. (*Metallurgical and Chemical Engineering*, vol. xiv, No. 6, March 15, 1916.)—About one year ago it had been proved that, with the proper X-ray equipment and correct time of exposure, blowholes and similar defects could be disclosed in solid metal of considerable thickness. Since that time the special equipment required for that kind of work has been further developed, and several factors essential to systematic and successful routine work have been established: proportion of required time of exposure to thickness of metal; dimension of smallest air inclusion that could be detected in a given thickness of metal; regulation of electric current to obtain maximum efficiency and the best results. Other points which had to be considered were to find the direction from which further progress in the application of X-rays to metallurgical work could be expected, and to establish the technic of metallography.

By ardent research work carried on in this country's finest laboratories, these problems were completely solved. The method has already been successfully applied to research work in connection with important metallurgical problems; for instance, that of casting copper. If copper is cast without additions, the metal is full of pores and blowholes, mechanically unfit, and of low electrical conductivity. The use of boron flax has remedied the difficulty of obtaining sound copper castings of high conductivity. In the difficult research problems of this work, X-ray investigations were applied with much success; stereoscopic radio-photographs of copper castings were taken, so that not only the size but also the relative depths of the pores could be studied. Without the use of X-rays it would have been necessary to machine off layer after layer of the many sample castings. Even then the experimenter would have had to build up a mental picture of the defects in his casting on the basis of what he had seen on each of the exposed layers. From the radiographs it was possible to see all these defects at once without destroying the castings.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

A PRECISION SHUTTER TESTING INSTRUMENT.†

By P. G. Nutting.

A PRECISION instrument for testing photographic shutters should provide means of determining the rate of opening and closing of a shutter as well as the time it is open. By merely projecting an image of the shutter upon a drum or disk having a photographic surface and rotating at a known speed, the time of opening may be readily determined. This method is in common use in many shutter factories.

For precision testing it is only necessary to interrupt the beam of light by which the shutter opening is photographed. These interruptions should be of a high and constant known frequency, and the duration of each flash should be very much shorter than the interval between flashes in order to obtain sharp images of the shutter opening. The literature of photography is full of descriptions of apparatus satisfying the above conditions to a greater or less degree. The testing instruments of Abney and of Campbell and Smith, of the National Physical Laboratory, are by far the best of those described, but each of these was open to objections so serious that the design of a new type for apparatus was considered advisable. In this the interruptions are at the rate of 1000 per second to within a maximum error of less than one-half per cent., the duration of an exposure is but 1/30,000 second, while the whole instrument is simple and inexpensive and easy to operate.

In the apparatus described the illuminating beam is reflected from a crown of 20 plane mirrors rotating at 50 revolutions a second. A small projection lantern supplies the light used, the condenser of the lantern focussing an image of the arc crater at the mirror surface. The reflected beam falls on a simple lens behind which the shutter to be tested is held in a universal iris

* Communicated by the Director.

† Communication No. 37 from the Research Laboratory of the Eastman Kodak Company.

holder. An image of the shutter is formed by a small camera lens (90 mm. E. F. L.) on a band of cinematograph film (negative) attached to the rim of an aluminum wheel 12 inches in diameter. This wheel, just before the shutter is snapped, is set in rapid rotation by means of a crank and gearing. It is enclosed in a light-tight box, so that wheel and box are readily lifted from the machine and taken to a dark room for loading and development.

The crown of mirrors is rotated at a very constant speed by means of a Leeds-Northrup governed motor making 1200 revolutions per minute. For determining speed, the shaft of the mirror crown carries a worm, and a single gear is arranged to be easily thrown into mesh with this. The revolutions of the gear wheel are counted with a stop-watch.

The duration of each flash is determined by the angular width of light beam at the lantern condenser. The beam at this point is limited by a vertical slit 2 mm. wide. The width of the beam as it flashes by the shutter opening is about one-thirtieth the distance between flashes, hence each exposure is about 1/30,000 second. Sharp shutter images were obtained even with film speeds so high as to give completely separated images of shutters fully open.

The three feet of film can take only about 50 shutter images without serious overlapping. To record shutter speeds of 1/10, 1/5, 1/2, and 1 second, the image is restricted to a narrow band by inserting a 1 mm. slit close in front of the moving film. To save counting the hundreds of images obtained at slower shutter speeds, one of the twenty rotating mirrors was painted black, thus rendering the shutter images in blocks of twenty.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

CANDLE-POWER MEASUREMENTS OF SERIES GAS-FILLED INCANDESCENT LAMPS.

By Ralph C. Robinson.†

THIS paper is an extension of one presented before the Illuminating Engineering Society (*Transactions of the Illuminating Engineering Society*, 11, 187–91, March 20, 1916).

The customary rating of incandescent lamps in mean horizontal candle-power is not satisfactory for gas-filled lamps, and is being changed to spherical candle-power, or lumens. The simplest way of doing this is to measure the mean horizontal candle-power and multiply by a suitable reduction factor. Small variations in the form of the filament, however, render this method inaccurate. Measurements have been made to show the variation in reduction factor for different filament positions. Four filaments of the customary spiral form, and having as nearly as possible the same spacing, diameter, leeds, and number of turns, were mounted in different positions—vertical, horizontal, diagonal, and V-shaped—and were run at the same average temperature of 2825° K. The mean horizontal candle-power was determined by taking measurements about the stationary lamp at intervals of 10°. Curves showing the candle-power distribution are given. The reduction factors obtained for the four filaments were 0.74, 1.01, 0.78, and 0.82 respectively, showing the very marked effect of variation in filament form. It is concluded that gas-filled lamps should be rated in terms of watts per spherical candle-power, as the variation in this value with change of form is very small.

The method of measuring the filament temperature by color match, and of photometering with the standard lamp running at low temperatures compensated by blue-glass screens. is outlined.

* Communicated by the Director.

† *General Electric Review*, 19, 323–6, April, 1916.

THE HOT CATHODE ARGON GAS-FILLED RECTIFIER.

By G. Stanley Meikle.*

CONDITIONS existing in a discharge tube equipped with a hot cathode in the presence of different pressures of gas have been investigated with reference to practical use as a rectifier. The high vacuum kenotron supplies currents up to 250 milliampères on 100,000 volts, but its drop of 100 to 500 volts prevents its use on low-voltage circuits. Introduction of positive ions neutralizes the space charge and so lowers the voltage required. But even traces of certain gases cut the electron emission to a small fraction. Moreover, the positive ion velocity then becomes so great that the cathode is rapidly disintegrated by bombardment. By proper adjustment of the pressure of a selected gas it has proved possible to practically eliminate disintegration, and produce a rectifier capable of handling currents from a few milliampères to high values at voltages ranging up to several thousand. Details of construction and cuts of several such rectifiers are given.

Certain impurities even in traces are very injurious, and substances are introduced which react chemically and so keep the gas pure.

Work in argon indicates that rectification is possible at all pressures. Increase of pressure raises the starting voltage and the cathode temperature required, but the voltage for operation is increased only slowly. At pressures between 3 and 8 cm. the disintegration of the cathode is at a minimum and the starting voltage is low.

The construction and connections of half-and full-wave rectifiers and of the self-starting device are discussed. The efficiency of the tube increases as the supply voltage rises. The arc drop with externally excited filament is from 4 to 8 volts, and the energy consumed in keeping the filament cathode hot is less than 40 watts. This makes the total energy consumed by a 6-ampère tube equivalent to that of a rectifier having an arc drop of from 10.66 to 14.66 volts.

The tubes operate satisfactorily on currents varying over a wide range, and can be started as low as 20 volts and maintained on 14 volts. The life of the low-current, low-voltage type varies from 900 to 3000 hours, and of the higher voltage from 500 to

* *General Electric Review*, 19, 297–304, April, 1916.

1000 hours. Many of the former have been in actual service for over 18 months. Oscillograms of the rectifying arc are given, showing, in all cases, perfect rectification.

THE PRODUCTION OF CONSTANT HIGH POTENTIAL WITH MODERATE POWER CAPACITY.

By A. W. Hull.*

THIS paper gives in much greater detail the material described under the title "A Powerful Source of Constant High Potential" (*Physical Review*, 7, 405–7, March, 1916).

A source of power, furnishing from 1 to 50 kilowatts at voltages between 10,000 and 200,000, and 5 kilowatts between 10,000 and 100,000 volts, with a voltage fluctuation in the latter case of less than 1 per cent., is described. The method avoids the use of electrostatic machines or low-voltage, direct-current generators in series, the only previous methods for producing constant high potential, with their inherent disadvantages, and rectifies high-tension alternating current by means of kenotrons. The direct current obtained is fed to a high-voltage condenser of sufficient capacity to supply the desired current during that part of each cycle when it is receiving none, with a voltage drop not exceeding a certain small amount. If a condenser of smaller capacity be used the fluctuations may be damped down by the use of another condenser and a choking coil.

The apparatus designed and used for over eight months in connection with investigations on X-ray spectra is described in detail, taking up in turn the generator, transformer, kenotron, condensers, inductance, voltmeter resistance, and the function of each, with discussion of the theory, and illustrative oscillograms. The fact that even in its present crude form the apparatus operates extremely well is a strong recommendation of the method. By use of a three-phase, 2000-cycle current and six kenotrons it would be possible with the present apparatus to furnish 100 kilowatts at 100 KV with the same constancy, and there is every reason to expect that this can be increased to 1000 kilowatts in the near future.

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* *General Electric Review*, 19, 173–81, March, 1916.

THE CHARACTERISTICS OF TUNGSTEN FILAMENTS AS FUNCTIONS OF TEMPERATURE.

By Irving Langmuir.*

SIMILAR material is given in each of the above references, but the second presents it in a more concise and convenient form, and omits most of the detailed discussion.

Any property of a filament which varies with the temperature may be used, after proper calibration, as a means of estimating the filament temperature.

Eighteen such properties are grouped, according to the knowledge of dimensions required for their use, under the headings:

1. Requiring no dimensions.
2. Requiring both length and diameter.
3. Requiring diameter only.
4. Requiring length only.

The method of application, mathematical relations, and advantages of each are discussed. A detailed study of the characteristics of tungsten filaments as functions of dimensions and temperature has been made, and the data obtained and those obtained by other investigators are discussed and compared. Experimental details are given and the results are collected and recomputed in tables giving:

1. Volt-ampère-candle-power characteristics and derived functions of tungsten filaments from 273 to 3540° K., corrected for cooling effect of leeds.

2. Specific resistance of tungsten from 300 to 3540° K.

3. Total emissivity of tungsten compared with the black body as a unit up to 3540° K.

4. Intrinsic brilliancy of black body as a function of the temperature in terms of the mechanical equivalent of light. Mechanical equivalent of 0.00121 watt per lumen found.

5. Brilliancy of black body from 1300 to 3500° K., comparing results of various investigators.

6. Emissivity of tungsten as function of wave-length and temperature from color of emitted light.

A formula for the approximate linear thermal expansion of tungsten between 1200 and 2500° K. is given.

* *Physical Review*, 7, 302–33, March, 1916; *General Electric Review*, 19, 208–12, March, 1916.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, April 19, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 19, 1916.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 8.

Mr. Charles E. Bonine, chairman of the Committee on Science and the Arts, reported the condition of the work of the committee.

The paper of the evening was presented by George R. Olshausen, Ph.D., of the Bureau of Standards, Washington, D. C., and was entitled "The Testing of Engineering Materials." The work done by the Bureau of Standards in coöperation with other organizations was described and detailed information was given of the elaborate series of tests on the strength of columns which were conducted at the Bureau. The apparatus used in these tests and the various types of columns tested were fully described and the results given in detail.

Experiments and investigations made with other materials, such as glass, steel rails, and bolts, were outlined.

After a discussion by Professors Marburg, Lanza, and others the thanks of the meeting were extended to the speaker.

Adjourned.

R. B. OWENS,
Secretary.

THE FRANKLIN INSTITUTE SCHOOL OF MECHANIC ARTS.

ANNUAL REPORT OF THE DIRECTOR.

1915–1916.

COURSES OF INSTRUCTION.

The ninety-second year of The Franklin Institute School of Mechanic Arts closed April 6, 1916. During the year classes were formed in Mechanical Drawing, Architectural Drawing and Design, Freehand Drawing and Water Color, Mensuration and Algebra, Plane Geometry and Trigonometry, Applied Mechanics, Strength of Materials and Structural Design, Steam Generation, and Theoretical and Practical Naval Architecture. A special class in Algebra was also formed during the second year.

REGISTRATION.

Large classes were enrolled in first year Mechanical Drawing, first year Mathematics, Naval Architecture and the special course in Algebra. The total registration in all Departments was three hundred and seven, an increase of about 15 per cent. over that of last year.

ATTENDANCE AND PROGRESS.

The high grade of work done by the students and their regular attendance indicate that the School has completed a satisfactory year. During the first term forty-six students made an average of 90 per cent., or over, and forty-two had a perfect attendance record. During the second term forty-two students made an average of 90 per cent., or over, and twenty-seven had a perfect attendance.

FACULTY.

Mr. Edgar P. Trask, of Wm. Cramp & Sons, was appointed to fill the vacancy caused by the resignation of Mr. H. C. Towle, former instructor in Naval Architecture, and Mr. B. A. Owen was appointed to continue the work of Mr. Elmer Bark in Mechanics. Mr. Wm. E. Bullock, who had been Assistant Director for four years, accepted a position in New York, and Mr. Simeon van T. Jester was made Assistant Director, at the same time continuing his work in Mathematics. No other changes were made in the Faculty, all other instructors meeting their classes as in previous years.

SCHOLARSHIPS.

Twenty-seven scholarships were available for students of the School; six of these were Bartol Scholarships in Drawing, derived from the B. H. Bartol Fund; sixteen scholarships were derived from the Isaac B. Thorn Fund and were awarded to students in Mathematics and Mechanics; the remaining five scholarships were offered by Hon. G. W. Edmonds.

PRIZES.

Valuable prizes were offered by Mr. Samuel M. Vauclain, Vice-President of The Baldwin Locomotive Works; by Mr. J. B. McCall, President of the Philadelphia Electric Company, and by Mr. Wilfred Lewis, President of The Tabor Manufacturing Company. Mr. Vauclain's prize is to be awarded to the student having the best record in the Department of Mechanics, Mr. McCall's prize to the student having the best record in the Department of Mathematics, and Mr. Lewis' prize to a meritorious student in the Department of Mechanics.

The Alumni Association continued its special prizes to the students having the best records and to students having a perfect attendance for the year.

VISITS.

Nine visits to places of engineering interest were paid on Saturday afternoons during the season, as follows: J. G. Brill Company, Milbourne Mills, Otto Gas Engine Works, The Curtis Publishing Company, Philadelphia Rapid Transit Company's Beach Power House, Philadelphia Electric Company's Station "J" at Tacony, Link-Belt Company, University of Pennsylvania, and Queen Lane Pumping Station.

HONORS.

Certificates for the satisfactory completion of a two-year course in one of the three Departments of Drawing, Mathematics and Mechanics are this year awarded to thirty-six students. The names of graduates for the season 1915–1916 are appended, as also are the names of those students to whom are awarded the scholarships and prizes indicated above, and of those granted certificates of Honorable Mention for regularity of attendance and proficiency in class work.

I desire to express my appreciation of the very efficient work done by the members of the Faculty and the hearty coöperation of the Committee on Instruction.

Respectfully submitted,

WM. H. THORNE,
Director.

April 14, 1916.

LIST OF GRADUATES, ETC., 1915-16.

CERTIFICATES.

CERTIFICATES ON THE SATISFACTORY COMPLETION OF FULL COURSES ARE AWARDED AS FOLLOWS:

MECHANICAL DRAWING.

Ellis Mortan Ayars
Howard A. Craig
Edward S. DeHart
Arthur H. Eilitz
Joseph Green
Andrew Hetherington
Robert Kauch
Bernard Lange
Alvin J. Lynch
Arthur J. Mannix
Charles Markert
Thomas Murtaugh
David Pascal
Abraham Rosenberg
Reuben Schmerling
George W. Williams, Jr.

ARCHITECTURAL DRAWING.

William Gronewald, Jr.
Clarence H. Jaggers
Joseph Matchett
John M. McAveney
Arthur J. Schwab, Jr.

FREEHAND DRAWING AND WATER COLOR.

George Frederick Smith

MATHEMATICS.

Daniel Batezel
Charles J. Culin
Raymond J. Davis
Fred Grube
Elwood L. Kieme
Myer Kratchman
J. P. Lyons
Raymond Mattis
William Münch
Arthur Rappaport
Otto P. Schuman

MECHANICS.

E. Victor Cooley
John L. Starr
John J. Stevenson

EDMONDS SCHOLARSHIPS.

WINTER AND SPRING TERMS.

George L. Dreeman, Mathematics
Harry Haering, Mathematics
Joseph Ritchie, Mathematics
George W. Williams, Jr. Drawing

BARTOL SCHOLARSHIPS.

DEPARTMENT OF DRAWING.

WINTER TERM.

E. Barrie Powers, Mechanical

SPRING TERM.

William Callingham, Mechanical
Harry E. Chaney, Mechanical
Leon Chatelaine, Architectural
Christian P. Kopp, Freehand
Henry J. Schmid, Mechanical

THORN SCHOLARSHIPS.

WINTER TERM.

Clarence E. Baittinger, Mechanics
Daniel Batezel, Mathematics
Joseph Hecking, Jr., Mathematics
Arthur Rappaport, Mathematics
William C. Schmoll, Mathematics
E. Victor Cooley, Mechanics
W. Gordon Cowan, Mathematics
Charles J. Culin, Mathematics
Otto P. Schuman, Mathematics
John L. Starr, Mechanics

SPRING TERM.

Clarence E. Baittinger, Mechanics
Fred Grube, Mathematics
Joseph Hecking, Jr., Mathematics
William T. Owens, Mathematics
Arthur Rappaport, Mathematics

MR. S. M. VAUCLAIN'S PRIZE.

MECHANICS.

E. Victory Cooley

MR. WILFRED LEWIS' PRIZE.

MECHANICS.

Albert Wm. Drobile

MR. J. B. McCALL'S PRIZE.

MATHEMATICS.

Charles J. Culin

NEW YORK SHIPBUILDING COMPANY'S PRIZE.

NAVAL ARCHITECTURE.

Albert L. Charbonnier

ALUMNI ASSOCIATION OF THE FRANKLIN INSTITUTE'S PRIZES.

AWARDED TO GRADUATES.

E. Victor Cooley,
Mechanics
Thomas I. Cooper,
Naval Architecture
Charles J. Culin,
Mathematics
Christian P. Kopp,
Freehand Drawing
Everett Barrie Powers,
Architectural Drawing
George W. Williams, Jr.,
Mechanical Drawing

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, April 5, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 5, 1916.

MR. C. E. BONINE *in the Chair.*

The following reports were presented for first reading:

No. 2657.—Paint and Varnish Remover.

No. 2667.—Dixie Magneto.

On the recommendation of the Sub-Committee on Literature, the following awards were made for papers in the JOURNAL, 1915:

No. 2662.—The Howard N. Potts Medal to Mr. W. S. Murray, of Hartford, Conn., for his paper entitled "Conditions Affecting the Success of Main Line Electrification," described by the sub-committee as an original and highly valuable contribution to an important phase of the transportation problem.

No. 2663.—The Edward Longstreth Medal of Merit to Mr. G. W. Fuller, of New York City, N. Y., for his paper entitled "Biochemical and Engineering Aspects of Sanitary Water Supply," described by the sub-committee as a comprehensive description of practical means of measuring the sanitary qualities of public water supplies.

No. 2664.—The Edward Longstreth Medal of Merit to Mr. Robert R. Abbott, of Cleveland, Ohio, for his paper entitled "Modern Steels and Their Heat Treatment," described by the sub-committee as a comprehensive statement of the best practice in the heat treatment of modern steels.

No. 2665.—The Edward Longstreth Medal of Merit to Major A. S. Eve, of Montreal, Canada, for his paper entitled "Modern Views on the Constitution of the Atom," described by the sub-committee as a lucid and comprehensive discussion of modern views on the constitution of the atom.

No. 2666.—The Edward Longstreth Medal of Merit to Dr. George F. Stradling, of Philadelphia, Pa., for his paper entitled "Modern Theories of Magnetism," described by the sub-committee as a comprehensive account of the modern theories of the phenomena of magnetism.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A joint meeting of the Section and of the Philadelphia Section of the American Institute of Electrical Engineers was held in the Hall of the Institute on Thursday, March 23, 1916, at 8 o'clock P.M.

Mr. Charles Penrose and Mr. Joseph H. Tracey presided jointly.

Dr. Harold Pender, Professor of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa., delivered a lecture, entitled "Recent Developments in Electrical Apparatus." This lecture dealt with the operating characteristics of the more important types of electrical apparatus lately developed in connection with the distribution and utilization of electric power. New types of transmission line equipment and accessories were described, as well as the latest forms of traction motors, phase converters, rectifiers, etc.

After the lecture Clarence E. Clewell, Assistant Professor of Electrical Engineering, University of Pennsylvania, gave a brief account of the progress in electric lighting and the development of the gas-filled lamp, which was followed by an interesting discussion of the lecture.

A rising vote of thanks was extended to Dr. Pender, and the meeting adjourned.

T. R. PARRISH,
Acting Secretary.

Mining and Metallurgical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday, March 30, 1916, at 8 o'clock P.M.

Prof. A. E. Outerbridge, Jr., occupied the chair.

The paper on "Some Problems in Physical Metallurgy at the Bureau of Standards," by George K. Burgess, Sc.D., Chief, Division of Metallurgy, Bureau of Standards, Washington, D. C., announced for this evening, was, due to Dr. Burgess's indisposition, presented by his associate, Dr. Paul D. Merica.

The lecture was fully illustrated with lantern slides and included references to the production of sound ingots and steel, failures of structural bronze, fusible boiler plugs, and the coöperative work of the Bureau of Standards with the American Institute of Metals on specifications for brasses and bronzes. The status of the investigation of railway materials at the Bureau was also described.

After an interesting discussion by Prof. E. Marburg, Professor Outerbridge, Mr. G. H. Clamer, and others, a vote of thanks was extended to the speaker and the meeting adjourned.

T. R. PARRISH,
Acting Secretary.

Mining and Metallurgical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday, April 6, 1916, at 8 o'clock P.M.

Prof. A. E. Outerbridge, Jr., occupied the chair.

Professor Outerbridge introduced Mr. Charles J. Gadd, Chief Engineer, American Iron and Steel Company, Lebanon, Pa., who presented a paper, entitled "Use of Powdered Coal in Metallurgical Processes." Mr. Gadd outlined briefly, with the help of lantern slides, the method of drying, conveying, and applying pulverized coal to metallurgical furnaces, and referred especially to the results obtained by the use of such coal in puddling, heating, and open-hearth furnaces with waste-heat boilers.

After an interesting discussion a vote of thanks was extended to the speaker and the meeting adjourned.

T. R. PARRISH,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, April 12, 1916.)

RESIDENT.

MR. LEONARD W. COLEMAN, superintendent, The Carson College for Orphan Girls, and for mail, 211 Lansdowne Avenue, Wayne, Pa.

MR. SAMUEL M. CURWEN, president, The J. G. Brill Company, Philadelphia, Pa., and for mail, Haverford, Pa.

MR. G. L. KOTHNY, consulting engineer, C. H. Wheeler Manufacturing Company, Eighteenth Street and Lehigh Avenue, Philadelphia, Pa.

MR. ROBERT SUCZEK, mechanical engineer, C. H. Wheeler Manufacturing Company, Eighteenth Street and Lehigh Avenue, Philadelphia, Pa.
MR. JAMES G. VAIL, chief chemist, Philadelphia Quartz Company, Chester, Pa.

NON-RESIDENT.

MR. CARL E. AKELEY, taxidermist and sculptor, American Museum of Natural History, 77th Street and Central Park West, New York City, N. Y.
MR. ALFRED E. WALLER, electrical engineer, 184 Archer Avenue, Mt. Vernon, N. Y.

ASSOCIATE.

MR. ARTHUR SYNNESTVEDT, student-at-law, 1201 Chestnut Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. C. G. BUCHANAN, 16 North Ninth Street, Newark, N. J.
MR. W. W. DAVIS, care By-Products Coke Corporation, McCormick Building, Chicago, Ill.
MR. JOHN P. EATON, 2642 North Napa Street, Philadelphia, Pa.
MR. E. HEITMANN, Belleview Terrace, St. Catharines, Ontario.
DR. CARL HERING, 210 South Thirteenth Street, Philadelphia, Pa.
MR. HENRY M. KOLB, 809 Widener Building, Philadelphia, Pa.
MR. P. M. LINCOLN, Railway and Lighting Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
MR. ROBERT RIDGWAY, care Public Service Commission, 120 Broadway, New York City, N. Y.
MR. GEORGE VON UTASSY, 449 Fourth Avenue, New York City, N. Y.
MR. F. R. WADLEIGH, 1110 Land Title Building, Philadelphia, Pa.
MR. G. A. WELLS, Fairoaks Farm, Darien, Conn.
MR. F. W. WESTON, 120 Broadway, New York City, N. Y.
MR. ARTHUR M. WILSON, 706 Stock Exchange Building, Philadelphia, Pa.

NECROLOGY.

JOHN McILHENNY.

1830–1916.

John McIlhenny, an early pioneer in the field of gas engineering, born in Philadelphia on April 22, 1830, passed away at his home in the Germantown suburb of this city on February 23.

His public school education was supplemented by a course in the night schools of The Franklin Institute and by an apprenticeship in the machine shop of the Southwark Foundry. About 1856, after a short experience in the Philadelphia Gas Works, under direction of that earlier master gas engineer, John C. Cresson, he superintended the building of the gas works in Wilmington, N. C., for the contractors, Perdicaris & Hoy, and for some years after the com-

pletion of that work he was engaged in similar undertakings for the same firm in various cities of the South. The beginning of the Civil War found him building the gas plant in Columbus, Ga., and there he made his home during the following twenty years. The last battle of the Civil War was marked by the burning of Columbus, leaving many of its people in a state of great destitution. In the reconstruction period which followed Mr. McIlhenny, together with his young wife, took a leading part in bringing order out of the prevailing economic and social chaos. He was several times elected Mayor of Columbus, and in that capacity started various municipal reforms, giving particular attention to the organization, in 1866, of a system of public schools, until then entirely wanting in that community. In this organization special provision was made for the children orphaned by the war, many of whom were growing up in idleness and ignorance, a menace to their own and the general welfare. The funds for this purpose were obtained by Mr. McIlhenny through special collections, to which he was always a leading contributor. The new system included schools for the colored children, and when, subsequently, the colored schools established by the Freedmen's Bureau were to be discontinued they were incorporated with the municipal system and continued by its Board of Trustees.

Various other new enterprises were started in Columbus by Mr. McIlhenny, including a cotton mill of his own, in which he instituted the ten-hour day when all other mills were working twelve.

He also led the way in the Sunday closing of saloons, and had the satisfaction of seeing his example followed in other cities of the state. One of the most notable results of Mr. McIlhenny's activity in Columbus was his early introduction of a high-pressure water service on its main streets to provide better fire protection than was being afforded by the existing system of cisterns and inadequate fire engines. He arranged for the use of a large pump, operated by water power at a cotton mill, and superintended the laying of the pipes, the cost to the city being scarcely more than that of the pipe itself. It brought about a great reduction in insurance rates in the district covered, and its value in that respect, as also its efficiency, attracted general attention. Various insurance companies sent representatives to Columbus to investigate the system, which thus became the precursor of the systems later developed in other cities for the same purpose.

Coming back to Philadelphia in 1877, Mr. McIlhenny, in addition to his business and professional activities, continued his interest in civic and communal affairs. He was one of the founders of the Pennsylvania Scotch-Irish Society and also of the National Society of that name, availing himself of the latter organization to promote the growing spirit of renewed harmony between the North and the South.

The death of his wife occurred but a little over a year before his own, two sons and three daughters surviving him.

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BOOK NOTICE.

CATALYSIS AND ITS INDUSTRIAL APPLICATIONS, by E. Jobling, A.R.C.Sc., B.Sc., F.C.S. Philadelphia, P. Blakiston's Son & Company, 1916. 112 pages, contents and index. 12mo. Price, $1.

This is a very interesting and useful summary of some of the more recent applications of catalysis, especially in inorganic chemistry. After a brief discussion of the history of the subject and indications of the principal types of catalytic action, specific descriptions are given of the application in the manufacture of sulphuric acid, chlorine, nitrogen compounds from the atmosphere, surface combustion, and of the effect of the small proportion of ceria on the Welsbach mantles. The actions of catalysts in connection with the hydrogenation of oils, synthetic operations with coal-tar products, the nature of the "drying" of paints are discussed. The transformation of carbohydrates and proteins, under the influence of the well-known enzymes, is considered very briefly.

The book is a compact and valuable summary of an important field of industrial chemistry and will repay perusal both by the technologist and general chemist.

HENRY LEFFMANN.

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CURRENT TOPICS.

Determination of Free Chlorine in City Water Supplies. G. A. LeRoy. (*Comptes Rendus*, vol. 162, No. 9, February 28, 1916.)—Water supplies in many towns are subjected to bacterial purification effected by the action of free chlorine, introduced in the form of alkaline hypochlorites, chloride of lime, or Javel water. Quite apart from any injurious effects on the system of free chlorine in drinking water, the odor and taste of water containing a greater quantity of free chlorine than 0.05 mg. per litre are objectionable. Hence the chemical control of waters so treated is important. Unfortunately the usual methods for the determination of free chlorine in water are inefficient and inoperative when the quantity of chlorine per litre falls below 0.05 mg. The method here proposed, capable of determining much smaller proportions of chlorine, is based on the partial freezing and concentration of the water to be examined. In freezing, the water separates as pure ice, leaving the chlorine concentrated in the remaining small quantity of uncongealed water. Under these conditions, using 10 litres of water, it is easily possible to estimate with starch-iodide mixture reagent 0.0005 mg. per litre.

This qualitative method may be made quantitative by precise determination of the original quantity of water and that uncongealed, and subjecting the latter to colorimetric comparisons with standard titrated solutions.

Propelling Machinery for Ships. W. J. Drummond. (*The Journal of the Institution of Mechanical Engineers*, March, 1916.)—When deciding on the type of machinery to be adopted in any ship, the most important general features are: reliability, economy of fuel, ease in manœuvring, and weight in relation to the power developed, the latter being particularly important in the case of warships. Above all other considerations, however, reliability must take precedence.

The engines of a ship often have to run without a stop for forty or fifty days, and the safety of the ship depends entirely on the ability of the engines to do the work required of them in a heavy sea and under circumstances never met with in land practice.

By far the commonest type of machinery afloat is the three-crank, triple-expansion condensing engine, supplied with steam by cylindrical boilers, and it is to-day a highly efficient piece of machinery. As compared with turbines, in two recent battleships in the United States Navy of about 20,000 horse-power, one equipped with turbines, the other with reciprocating engines, the reciprocating-engined vessel maintains a distinct lead in economy of fuel. An arrangement which is the logical outcome to use steam down to as low a

pressure as possible, and has been used successfully on many of the largest steamers built, consists of two triple-expansion engines taking steam direct from the boilers and exhausting into a low-pressure turbine. In many cases the turbine receives steam at less than atmospheric pressure and develops from one-quarter to one-third the total power. When the vessel is under way astern, the turbines revolve *in vacuo*, the steam from the reciprocating engines passing direct to the condensers.

In England, the direct-coupled turbine in large, high-speed vessels more than holds its own, compared with reciprocating engines, and efforts are principally directed towards adapting them to slower-speed vessels. To do this successfully, the propeller must run at 80 to 200 revolutions, while for maximum efficiency the turbine must run at 2000 to 3000 revolutions. Geared turbines have been employed to meet these conditions, and in several cases of direct comparison with vessels fitted with triple-expansion engines the geared turbine vessels have shown superior economy of fuel. One of the objectionable features of the early geared turbines was the noise. By careful design and workmanship noise and vibration have been much reduced.

The two chief rivals of mechanical gearing are the Föttinger transformer and the electric drive. The Föttinger transformer has been developed in Germany by the engineer whose name it bears. It consists, briefly, of a high-speed turbo-centrifugal pump and two water-turbines designed to run in opposite directions and at a lower speed of rotation than that of the pump. These are all incorporated in one casing; the steam-turbine drives the pump, the water from which drives either water-turbine at will, both being rigidly connected to the propeller shaft. This device possesses great flexibility, but its efficiency is considerably lower than the geared turbine, being 90 per cent., as against 98½ per cent. for the hydraulic gear.

The electric drive has had its chief development in the United States, a successful installation in the collier *Jupiter* having demonstrated the feasibility of installing the system in the battleship *California*. Possible danger from faulty insulation and increased complication are the chief objections to this system.

Boilers on board ship fall into two main divisions—ordinary cylindrical or Scotch boilers, and the numerous types of water-tube boilers. From a naval point of view the cylindrical boiler takes up too much room, is not sufficiently adaptable to rapid variations demanded in the supply of steam, and takes too long to raise steam. With water-tube boilers on turbine-driven destroyers, the time of getting under way, starting from a cold ship, is that necessary to warm the turbines thoroughly, and has been known to be as little as twenty minutes.

Oil fuel is in limited use for steaming purposes, mainly in warships. For steaming purposes it has the important advantage of meeting large and sudden demands for power. A type of engine

which may make the use of oil fuel more general in the merchant service is the Diesel. A limited number of Diesel engines have been fitted on board ship, but they are all of comparatively low power.

An Enclosed Cadmium-vapor Arc Lamp. H. J. S. SAND. (*Proceedings of the Physical Society of London*, vol. xxviii, part ii, February 15, 1916.)—The yellow sodium doublet and the lines emitted by the mercury-vapor arc have hitherto usually been employed in those branches of physical inquiry in which a powerful light of well-defined wave-length was needed. The great importance of having further lines at our disposal, particularly for the measurement of rotary dispersion, has been emphasized recently by Lowry, to whom we owe the introduction of the mercury arc in polarimetric work; and the use of the cadmium lines was recommended by him.

The author's design of a cadmium-vapor lamp is the product of several years' experience gained in attempts to construct such a lamp that would meet the requirements of a laboratory appliance as completely as possible. The lamp is constructed of quartz glass and, in general construction, is similar to the well-known mercury lamp. It consists essentially of a quartz tube bent into an inverted U in such a manner as to form a short cathode chamber and a long anode chamber. To start the lamp, the metal is melted by means of a Bunsen burner, and the arc is struck by tilting. Before introduction into the lamp, the metal is freed from oxide and dissolved gases by a special process of filtration while at the pump. When started from the cold it usually lights up even before tilting. It was generally run on a lighting circuit of 100 to 200 volts, with a back resistance adjusted to a current of 5 to 7 ampères on short circuit. The potential difference at the terminals of the lamp is low, usually about 30 volts. The metal distils over from the lower hotter anode chamber into the upper cathode chamber and the metal drips back again over the bend of the U every two or three minutes, causing a slight flicker which, however, does not interfere with the use of the lamp. The metal is prevented from adhering to the glass, which might lead to fracture, by the pressure of a small amount of loose powder (zirconia) in the lamp. When once started the lamp will continue to burn indefinitely and gives a powerful light.

Photographs in Relief. E. CONSTET. (*Revue Generale des Sciences*, 27th year, No. 4, February 29, 1916.)—In 1899, Andresen pointed out the property possessed by hydrogen peroxide of dissolving both the reduced silver and the gelatine substratum of a photographic plate. This effect, however, sometimes took place very slowly, even with very concentrated hydrogen peroxide, 15 to 24 hours being required. The author has demonstrated that the action may be made to take place in a few minutes if several drops of acetic acid are added to the peroxide bath or if the bath is composed of water, 100 c.c.; hydrochloric acid, 10 c.c.; barium dioxide, 4 gm.

The dissolution of the image takes place in a selective manner, the dense parts of the image being more readily attacked than those containing a proportion of the unreduced salts. This action results in the formation of an image in relief inversely proportional to the opacity of the metallic deposit. Another bath for producing this effect has been patented by Belin and Droillard, consisting of hydrogen peroxide to which are added nitric acid, sulphate of copper, and bromide of potassium (French patent No. 423,150).

If the negative has not been previously fixed in hyposulphite, a positive image is obtained, the differences of shade being represented by varying thicknesses of unattacked gelatinobromide of silver. By simple absorption of aniline colors the positive image may be made to assume any tint. The thick parts of the gelatine relief absorb a relatively considerable quantity of the coloring matter, and the thin parts proportionally less. Prints on paper can be obtained from such a colored relief plate while damp by simple contact. To this end, a paper coated with a thin layer of hard gelatine is employed; for example, that known as *simple transfer* in the carbon process. Two or three prints may be so obtained from one soaking in the color-bath, after which the plate must be returned to the bath for an additional supply of color. Photoprinting plates may also be made from the relief by the stereotype process.

Optical Appliances in Warfare. C. R. DARLING. (*Journal of the Royal Society of Arts*, vol. lxiv, No. 3303, March 10, 1916.)—Optical appliances used in warfare comprise a large number of separate items, but those which are of paramount importance in military operations and in general use may be classified as follows: (1) Field-glasses and telescopes; (2) searchlights; (3) periscopes; (4) range-finders; (5) signalling lamps and heliographs. In addition to these, cameras, prismatic compasses, surveying instruments, etc., are used, but only those devices especially devoted to warfare embraced in the above five headings will be considered.

As an aid to vision, field-glasses or telescopes are essential in military operations, and a number of different patterns, varying according to circumstances, are in use. Binoculars on the principle of the Galilean telescope possess several drawbacks as compared with modern prismatic glasses, notably that the field of view is small and the magnification low, and also that cross-wires cannot be introduced, owing to the fact that no real image of the object is produced. On the other hand, they give good illumination, and in a dull or dark atmosphere may be used to advantage. Patterns with magnifying powers of three, four, and five respectively are in use, having fields of view ranging from about 3° to 4° 30′.

The prismatic binoculars introduced by the firm of Zeiss have the advantage of a long-focus object-glass mounted in a short body, an increased field of view by placing the object-glasses farther apart than the eye-pieces, and that a real image of the object is formed, enabling

cross-wires or graticules to be used. Patterns are issued with magnifying powers of six and eight, with fields of view ranging from 4° 40′ to about 8° 30′, a marked advantage over the Galilean type. In some of these, graticules are fitted in the focal plane of the object-glass. These consist of a number of lines ruled on a glass plate, spaced out so as to represent minutes of deflection to right or left, which assist in accurately determining the position of the object in the field of view. If rotated through a right angle, the graticules may be used similarly for elevated objects, the dimensions of which may be thus estimated.

A number of different kinds of telescopes, fitted with special devices, are used either for general observations or as distinctive parts of instruments, such as directors on gun-sights, the magnifying power ranging from three to thirty-five. In some patterns the magnification may be varied over a wide range—from five to twenty diameters—by a single movement, without disturbing the focus of the sighted object. When telescopes are used for gun-sights, a pointer or sighting-wire is placed in the focal plane of the object-glass where the image of the target will be formed, and when the image is seen to coincide with the assigned mark the aim is correct. This method of sighting is preferable to the alignment of the target with the fore-sight and back-sight, as the eye cannot be focussed upon all three points at once.

The searchlight does not play a prominent part in land warfare under present conditions, as it would be too conspicuous an object, and when illumination is required star-shells are used. As a means of sighting air-craft, for coast defence, and for naval purposes, however, the searchlight is indispensable. The source of light is an electric arc at the focus of a concave mirror. As the focus of the mirror is a point, it is evident that only one point of the crater of the arc can occupy this position, and rays emanating from this point, after reflection, will proceed in lines parallel to the mirror. From all other positions of the crater the rays will be reflected from the mirror at an angle with the axis, the value of which under working conditions is 2 or 3 degrees. Although glass mirrors, silvered on the back surface, by which spherical aberration is corrected, have been used, they have been abandoned on account of their liability to breakage, and paraboloid mirrors made of metal are now used, the reflecting surface being of silver or gold, or occasionally of palladium or nickel.

The combination of two 45-degree mirrors mounted in a frame, used for viewing over a parapet without exposing the observer, is frequently referred to as a periscope. Strictly speaking, a periscope is an instrument in which the entire horizon may be viewed through a fixed eye-piece. For naval work, and particularly for submarines, these instruments are invaluable, as observations may be made with nothing but the top of the instrument projecting above the water. A periscopic gun-sight also enables guns to be laid under cover, and enables auxiliary marks to be used without the gunner having to

change his position. In principle it consists of a vertical tube containing reflecting prisms and an objective. Horizontal light-rays are reflected vertically downwards, then horizontally to an eye-piece.

Range-finders, in principle, depend generally upon the estimation of the distance of the target from a point in a base line of known length. Knowing the bearings of the target from the extremities of the base line, the lengths of the other sides of the triangle can be either determined by computation or by a direct calibration of the angular setting into orange when one of these angles is a right angle. The instrument most widely used for range finding is that of the type introduced by Professors Barr and Stroud. It gives satisfactory results as to accuracy, and is compact, having a total length of less than four feet. It has also the very considerable advantage of requiring only one observer. The trigonometric principle is also employed in this instrument. The base line is the distance between two objectives at the end of a tube which form two separate images, one erect, the other inverted, separated by a horizontal line, and viewed by an eye-piece at the centre. Coincidence of similar points of the two images at the line of separation is secured by the movement of a prism in one side of the optical system. The amount of this movement is a function of the range which is read from a calibrated scale adjacent to a pointer attached to the movable prism.

In trench warfare, signalling by flags, heliograph, or lamps is not generally resorted to, the field telephone being better adapted for communication under these conditions. In open warfare, however, the heliograph is useful for flashing signals by the aid of sunlight. It consists of a circular flat mirror, five inches in diameter, capable of being tilted through a small angle by means of a key, and possessing a sighting-vane for laying on to the receiving station. The Morse code is used, short flashes representing dots, and sustained flashes dashes. For night work signalling lamps are used, a parallel beam of light being sent out which can be cut off by a movable shutter.

Potash from Kelp. I. F. LAUCKS. (*Metallurgical and Chemical Engineering*, vol. xiv, No. 6, March 15, 1916.)—The scarcity of potash due to the war has caused great interest to be taken in many of its possible sources. One of these is the growths of kelp on the Pacific coast. Much has been written on the subject, but very little information is available on the gathering and treatment of this material to transform it into a marketable product. Before this year most of the companies attempting to develop the kelp industry have been of limited capital. Only lately have several concerns with adequate resources to carry on their development to a successful issue engaged in the industry, so that at the present time a limited amount of dried kelp is being produced, and very considerable increase in this production may shortly be expected. The author has had direct charge of large-scale operations, harvesting, transporting, and drying kelp, and his records are the results of actual experience.

This experience has been confined entirely to the kelp of Puget Sound, but, outside of the composition of the plants, most of the experience would be applicable to California kelp as well.

The green kelp plant is mostly water, analyses having shown as high as 95 per cent. water. The average is probably between 92 per cent. and 93 per cent. The important question in the utilization of kelp has always been the cost of harvesting. There was no reliable way of prophesying what it would cost to go out in the ocean, cut a plant below the surface of the water, get it aboard a scow, and land it. The other features of the process were well known. Data on drying costs, leaching, crystallizing, etc., were available, but no one had ever before harvested a marine plant in hundred-ton lots. There have been a number of different types of machines proposed for cutting kelp, including reciprocating knives, revolving blades, band saws, etc., but, so far as the writer is aware, the only method that has been tried in actual practice is that of reciprocating knives (like a mowing machine). These operate several feet below the surface of the water and may be made as wide as desired. A conveyor of some type is usually placed behind the knives to carry the cut kelp aboard the scow. After it is aboard it is generally chopped into shorter lengths by various machines, and piled either on the scow which carries the cutting mechanism or on another scow alongside. The cost of harvesting with an equipment of this kind amounted to 43 cents per ton, which includes the relatively large towing charge of 32 cents per ton. The latter can be reduced considerably by mounting the cutting machinery on a self-propelled barge. Unloading by hand costs 6.3 cents per ton, but this can be reduced to less than 1 cent per ton by the installation of a conveying system on the deck of the scow. The cost of drying will vary between 25 and 50 cents per ton of green kelp, depending on the fuel used, cost of power, size of plant, etc.

It is not necessary to go further than the dried kelp to obtain a marketable product. The potash and nitrogen are salable on a unit basis. Assuming 28 per cent. chloride of potash and 2 per cent. nitrogen in the dried material, about 60 per cent. of the weight is practically valueless. If the material is shipped from the Pacific coast to the Atlantic by water, the nitrogen will just about pay the freight in ordinary times. If the potassium chloride is concentrated from the balance, the nitrogen can be sold on the Pacific coast and 70 per cent. of the freight saved on the potash. With the present high price of potash, the drying of kelp is a very profitable business. Such conditions will enable the industry to get a start and work out its problems. With normal prices of potash, kelp must be worked in plants of large capacity, well designed, with a minimum of labor, every possible economy effected, and all of the profitable by-products saved. It would seem unlikely that the price of potash will be lower for some time than it was before the war. If the price remains above $35 per ton for 80 per cent. muriate of potash, kelp can be worked at a profit in a properly-designed plant.

Fuel Briquet Industry in 1915. ANON. (*U. S. Geological Survey Press Bulletin*, No. 267, April, 1916.)—Over a million dollars' worth of briquets were made out of waste coal dust in 1915, the exact production being 221,537 short tons, valued at $1,035,716. This was the largest output in the United States for any year with the exception of 1914. The manufacture of this type of fuel is, however, still in its infancy, and according to C. E. Lesher, of the United States Geological Survey, a good many years will probably elapse before the briquet industry assumes very large proportions. The work of briquetting this low-grade material and converting it into fuel suitable for higher uses is, however, practicable conservation, and as such deserves far more attention than it now receives in this country. European countries, more thrifty in their use of coal, have developed the briquetting industry to large proportions. Most of the mechanical difficulties of manufacture have been solved in this country, and the future growth of the industry now depends upon the development of markets for the product. The producing plants are, however, so widely distributed and the total production is so small compared with that of other kinds of fuel that the conditions affecting the market for the output of each plant are more or less local and peculiar. In general, in the East, briquets compete with anthracite as domestic fuel, and nearly all the output of the eastern plants is manufactured from anthracite culm. The people of the eastern cities, accustomed to the incomparable anthracite, have not taken very kindly to these briquets, probably largely because of the volume of tarry smoke given off by nearly all kinds of briquets when they are first ignited, and perhaps partly because it has not been possible to offer them at a price enough lower than that of anthracite to induce their extended use. Being made from the cheaper sizes of anthracite, the briquets contain a greater amount of ash than the domestic sizes, and, although this ash does not clinker in the furnace, it reduces the heat value of the fuel.

There were 15 briquetting plants in operation in the United States in 1915, one less than in 1914. One new plant in California reported an output in 1915, and two plants, one in New Jersey and one in New York, ceased operations. The greatest increase in output was made on the Pacific coast, the central states recording little change and the eastern states a large decline in output.

Strontium in 1915. (*U. S. Geological Survey Press Bulletin*, No. 267, April, 1916.)—The manufacturers of red fire and of beet sugar are said to have shown considerable interest in domestic strontium deposits during the last year. If sugar holds its present price the beet-sugar makers might perhaps profitably substitute the strontia method for the one they now use, but the substitution will require considerable time and its economy must depend on several economic factors which are unknown to the United States Geological Survey, by

which the statistics of the industry are compiled. The returns received by the Survey do not show that any strontium-bearing ores of domestic origin were sold in 1915 or that any American deposits were exploited.

The deposits in northwestern Ohio and southeastern Michigan seem to be the best available for early exploitation. Celestite, a strontium mineral, is reported to occur in workable quantities in certain limestone quarries near Toledo, Ohio, though it is not now recovered. The mineral is found in broken and open beds of dolomite, or magnesian limestone. The installation of expensive machinery for its recovery is hardly warranted, but the larger pieces of celestite could be easily hand-sorted from limestone on picking belts, or possibly on the ground, and would probably find a market.

Large deposits of celestite occur in Arizona and California, but they are far from markets and of low grade as compared with commercial ores now used. Plants for making commercial strontium compounds may eventually be built at places where both these sources could be drawn upon, but the development of these deposits must wait on the decision of the sugar refiners to adopt the strontia process.

Most of the commercial ores used in making strontium salts are of high grade, containing at least 95 per cent. strontium sulphate. English celestite is at present largely used on the eastern seaboard and is laid down at the works at about $12 a ton, so the owners of deposits of strontium ores must not hope for large profits on their crude material.

The principal commercial strontium salts are strontium hydroxide, used in the beet-sugar industry, and strontium nitrate, used in pyrotechnics, in which, however, strontium chloride is also used. Small quantities of certain organic and inorganic salts, such as acetate, lactate, bromide, iodide, arsenite, and phosphate, are used in medicine.

Strontium nitrate was formerly used in making some types of smokeless powder, but the powder companies, it is said, now use the salts of strontium only for making illuminating or signal shells, in which the value of the strontium lies in the brilliant red color it imparts to the flame produced by explosion.

The imports of strontium oxide, protoxide of strontium, and of strontianite, or mineral carbonate of strontia, in 1914, as reported by the Department of Commerce, were valued at $1016, and in 1915 at $6411. The imports of celestite (strontium sulphate) used by domestic manufacturers of strontium salts are not recorded, as this mineral is classified with other chemicals not specially provided for. Strontium salts are imported free of duty.

The United States Geological Survey has now in press a report by J. M. Hill on barytes and strontium in 1915, a copy of which may be had, when issued, on application to the Director, United States Geological Survey, Washington, D. C.

Preparation of Tungstic Metals. H. FLECK, before the Colorado Scientific Society. (*Mining and Scientific Press*, vol. 112, No. 4, January 22, 1916.)—The metal is prepared in two forms; namely, powder and ferro-tungsten alloy. Much discussion has arisen regarding their respective advantages, especially with reference to the relative waste incurred during introduction of each form into the steel bath. Apparently no decision has been reached, since both forms are manufactured, although about 85 per cent. of the tungsten is made into the ferro-alloy. Powdered tungsten is fed into the bath by means of an enclosure in steel tubes, in order to prevent oxidation of the tungsten. The manufacture of powdered tungsten first demands a preparation of tungstic trioxide from the ore and then reduction at high temperature with some pure form of carbon. A rather coarse, steel-gray, dense tungsten results, which, with care, may have its carbon content kept within 1 per cent.

Ferro-tungsten is made mostly from the concentrate direct by electric-furnace treatment. It contains from 50 to 80 per cent. tungsten. Carbon, in the form of coke, is the common reducing agent. Hematite is used subsequently as a decarbonizer.

Portable Equipment for Thawing Frozen Pipes. ANON. (*Electrical World*, vol. 67, No. 12, March 18, 1916.)—A gasoline engine directly connected to a low-voltage direct-current generator, a switchboard, and a reel of cable assembled on a small truck make up an outfit that is being effectively used by the water-works department of the city of St. Paul, Minn., to thaw out frozen water pipes. The generator is rated at 20 kilowatts at 40 volts, and is driven by a four-cylinder, four-stroke-cycle gasoline engine. A voltmeter, an ammeter, a rheostat, and a single-pole knife switch of 500 ampère rating are mounted on the switchboard. The reel holds 500 feet of flexible copper cable of 300,000-circ. mil. cross-section in 100-foot lengths. Each length is fitted with terminal lugs. The various parts are attached to a steel frame, which is mounted on a 1.5-ton trailer hauled by a motor truck. The mounting is temporary, so that after the winter season the thawing unit may be removed and the trailer used for other purposes.

In operation, the positive terminal of the generator is connected through a section of the cable to the frozen pipe in the building between the meter and the street main and the negative terminal to the nearest outside fire hydrant, so that the circuit is through the lead or iron service pipe and the main to the hydrant. After the cables are connected, the engine is started and the voltage built up to between 30 volts and 40 volts, when the main switch is closed. A current flow of about 250 ampères is maintained for two or three minutes and then increased to 350–500 ampères, depending upon how badly the pipe is frozen. Under these conditions it is reported that the service line has been cleared in all cases within ten minutes.

The Pipe- and Reed-organ Industries. J. C. FREUND. (*The Piano and Organ Purchasers' Guide* for 1916.)—Pipe-organs (almost invariably for churches) were built long before an effort was made by Americans to construct reed-organs. Up to about fifty or sixty years ago we still imported most of our reed-organs, melodeons, or harmoniums, principally from France. About 1850, however, the American reed-organ manufacture really began and soon surpassed the European product in importance and quality. The church- or pipe-organ industry has also made great progress, and we have manufacturers who design and erect instruments that can compare favorably with the best made in England, France, Germany, and Italy—countries which long enjoyed supremacy in this product. The extraordinary improvements in reed-organs from the days of the old primitive melodeons have acted somewhat as a bar to progress in church-organ building, particularly as the cheaper price of the reed-organ made it more popular in communities where economy is a serious object in purchasing an instrument for a church or chapel. Recently, however, great strides have been made by the western as well as the eastern church-organ builders. Electrical mechanism has been extensively developed, and with it corresponding economies in manufacture have enabled the builders to lower costs.

Most of the notable improvements and inventions in church-organ building have been made by Americans. Up to the year 1835 the reed-organ industry in the United States had made no great progress, such factories as there were being confined to Boston and the New England towns. For a long time the East controlled the market in reed-organ making, but later the West became a great reed-organ producing territory, with Chicago as the centre. By the year 1870 the American reed-organ had driven foreign instruments out of the market.

The two radical improvements from whose invention dates the superiority of the American reed-organ are, first, the discovery that by giving the tongue of the reed or vibrator a peculiar bend or twist the quality of the tone was improved. This process is known as "voicing." Previous to this all reeds had been left flat or straight, so that the tone produced was thin and reedy, as in the foreign-made instruments. The second improvement was in the substitution of an exhaust system for the pressure system used by the English, French, and German instruments. Some houses of distinction have of late years brought out reed-organs of large size which are only surpassed in volume and beauty of tone by the larger pipe-organs. Constant efforts have also been made during the last twelve or fifteen years to produce self-playing organs, using perforated rolls similar to those of the piano-player, and within the last few years these efforts have met with marked success.

Rapid Nickel Plating. O. P. WATTS. (*Proceedings of the American Electrochemical Society*, April 27–29, 1916.)—During the greater part of the half century that nickel plating has been practised, platers were content to follow in the footsteps of their forefathers and deposit nickel at the slow rate of three to five ampères per square foot. A few years ago "rapid nickel salts," claimed to permit nickelling at two to three times the usual rate, were imported from Europe. These proved to be mixtures capable of yielding more concentrated solutions than that enemy of progress, the "double sulphate," which for so long has masqueraded as the plater's friend. The American plater soon learned how to make up his own rapid solution, and as a result nickelling at ten to twenty ampères per square foot is very common to-day.

Recent achievements in plating with cobalt at 150 ampères per square foot, turning out commercial plating of high grade in three minutes, suggested the desirability of obtaining similar effects with the cheaper nickel solution. In so far as the wonderful results in cobalt plating depend upon the extreme concentration of the solution (312 grammes of anhydrous cobalt sulphate per litre), it should be possible to duplicate them with nickel, since its salts are equally soluble. It is in the matter of anode corrosion and in its absorption of hydrogen that nickel is inferior to cobalt as a metal for electroplating. The nickel anode becomes "passive" on the slightest provocation, and, instead of all the current dissolving nickel as desired, a portion of it is spent in producing acid at the anode. Besides cutting down the efficiency of deposition, this acid causes hydrogen to be evolved in considerable quantity on the cathode, where some of it is absorbed by the deposit. Absorption of hydrogen by nickel renders it hard and brittle, and is likely to cause it to curl away from the metal on which it is deposited. The addition of a small amount of chloride to the sulphate solution usually used for nickel plating is a well-known remedy for this passivity of the anode.

Previous experience with hot nickel solutions indicated their use for overcoming the difficulties mentioned, since, in hot solution, anode corrosion is greatly improved and absorption of hydrogen lessened. (1) Heating from 25° to 70° C. lessens the resistance of the solution one-half. (2) The current density may be increased two and a half to three-fold. (3) If less than 100 per cent. in the cold solution, the current efficiency is raised. (4) Anode corrosion is greatly improved and higher current densities may be used at the anode as well as at the cathode. (5) The deposit is superior to ordinary nickel plate in toughness and freedom from peeling. (6) In the solution tested, plating may be done at 200 to 300 ampères per square foot, at which rate the same amount of metal is deposited in five minutes as requires one and a half hours in the "rapid solutions" now in use at ten ampères per square foot.

Getting Potash from Brines. ANON. (*United States Geological Survey Press Bulletin*, No. 233, March, 1916.)—The urgent need of a domestic supply of potash salts has greatly increased since the importations from Germany were stopped. During this time the price of high-grade potash has advanced from $39 to about $500 a ton. Meanwhile efforts to find commercially workable deposits of potash in this country have been eagerly and diligently made, both by private capitalists and public agencies. The United States Geological Survey, appreciating the needs of the manufacturers and farmers of this country, has endeavored both to find deposits of soluble potash salts and to discover practicable methods of extracting potash from rocks that carry relatively large proportions of potassium. Every clue that might yield valuable results has been followed up in a country-wide investigation, extending from New York to California. The Geological Survey, in its search for potash, has sunk several deep holes in the deserts of Nevada and is now drilling one in the panhandle of Texas.

The Geological Survey is also making some laboratory experiments designed to aid in discovering a cheap process of separating potassium salts from natural brines. In these experiments special attention has been given to the evaporation of brines rich in potassium. The results of some of the earlier work were published late in 1915 as Professional Paper 95–E. More recent experiments have been made with the natural brine from Searles Lake, Cal., which contains the equivalent of nearly 12 per cent. of potassium chloride in the solid salts. The results are given in a recent Survey publication, "Evaporation of Brine from Searles Lake, Cal.," by W. B. Hicks, issued as Professional Paper 98–A. This report shows the changes in the composition of the solution resulting from the evaporation of the brine, the composition of the crystals deposited from the hot solution during evaporation, and the composition of the crystals deposited when the solution was cooled. A copy of the report may be obtained free of charge by addressing the Director, United States Geological Survey, Washington, D. C.

The data recorded indicate that carefully-controlled fractional evaporation and crystallization, possibly combined with other treatment, promise much as a means of obtaining potassium from brines similar to that of Searles Lake. Further study of the behavior of the constituents of the brine under varying conditions may be made.

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